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FINAL ENGINEERING REPORT NO. 607

10^6 BIT ENGINEERING RECORDER/REPRODUCER

Contract No. 950105, Modification #2, Phase I

Reference: REL Technical Proposal Dated June 5, 1961

(REL W.O. 744)

To

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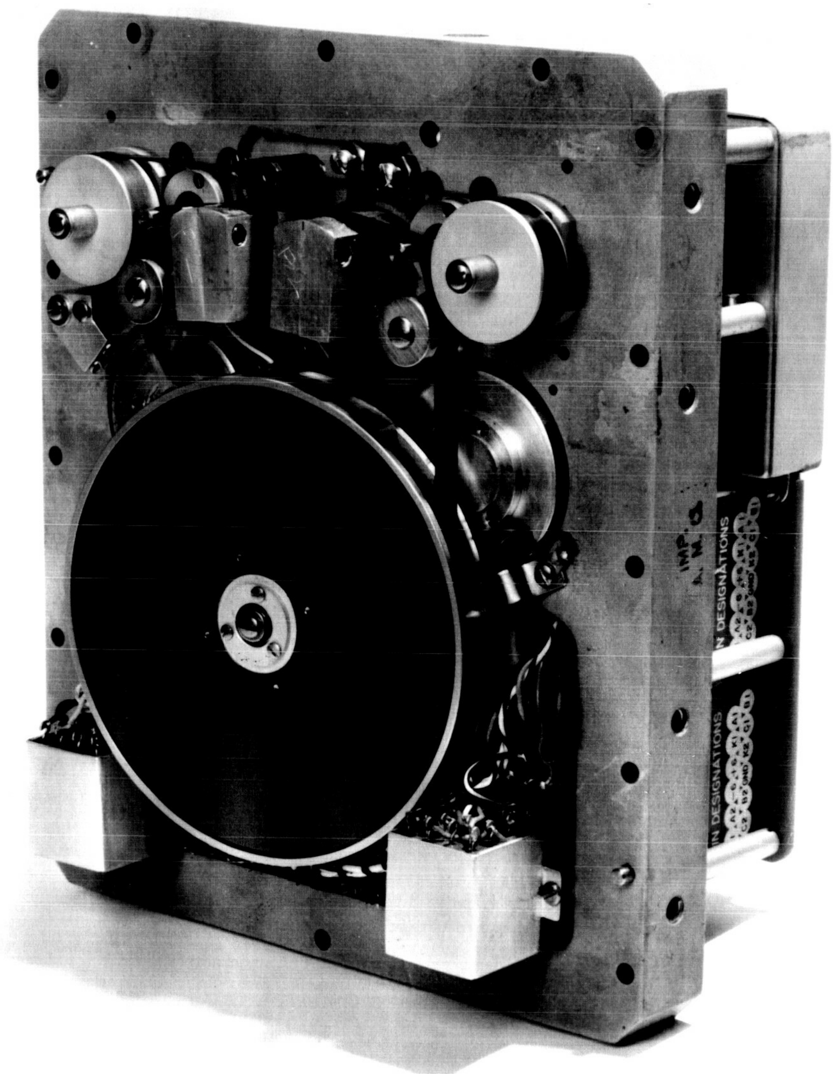

10^6 BIT RECORDER

ENGINEERING MODEL

Final Engineering Report
Jet Propulsion Laboratory
REL Report No. 607, REL W.O. 744

TABLE OF CONTENTS

TABLE OF CONTENTS (Con't.) — Page

TABLE OF CONTENTS (Concluded) Page

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FINAL ENGINEERING REPORT

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I SUMMARY

10685

This report describes the results of the subject program as of its conclusion, July, 1962. It includes a discussion of the chief problem areas, a description of the mechanism developed as part of the program including performance data, and recommendations for additional steps to be taken should the particular design be intended for flight use.

During the project, JPL was furnished with monthly technical progress reports, and, at the conclusion, with a complete set of engineering drawings. The reader may refer to these reports for additional technical and historical information, and to the drawings for more complete descriptive details of the final design.

II PURPOSE OF PROGRAM

The program, primarily developmental, was intended to investigate the following problems, and, based on the solutions to these problems, to result in the fabrication of a magnetic tape recorder/reproducer which fulfilled as many as possible of the requirements detailed in JPL Specification #30474A for use in Mariner planetary space vehicles. These problems were (1) a general study of the effects of thermal bacteriological sterilization on a transport mechanism and its electronics, (2) reproduction of NRZ binary data at an extremely low tape speed which results in a playback-head output less than 100 microvolts peak-to-peak, (3) absolute synchronism and lack of jitter in the reproduced output by means of a phase-locked tape speed control, and (4) minimum size, weight, and power consumption in the final design. ABSTRACT

III RESULTS OF PROGRAM

In summary, it may be stated that the program was generally successful. Means were found to surmount the major problems mentioned in paragraph II, which resulted in fabrication of a suitable mechanism and electronics. Size and weight of the finished product were somewhat greater than specified, but these could be reduced in flight model designs. As explained in a subsequent section, shock, noise vibration, and radio interference tests were not performed. Although it is not expected that these tests would demonstrate unforeseen difficulties, they should be performed prior to engineering of flight models of similar electrical and mechanical configuration. Every effort was made to insure long life, but this can be proven only through use.

The single mechanism fabricated as part of the program was not intended as a flightworthy unit. Because of modifications during assembly and subsequent extensive testing, the mechanism is being retained by REL as a test vehicle to aid future programs for JPL rather than attempt to rebuild it to a flightworthy condition. Pending other needs for the particular mechanism, we intend to keep it operating as much as possible and, when convenient, subject it to ambient temperature variations as well.

IV PROBLEM AREAS

A. It was anticipated at the beginning (1) that studies would be required of sterilization problems and application of phase-locked-loop techniques to tape speed control; (2) that design of suitable playback amplifiers would be hindered by the low-frequency, low-amplitude signals reproduced by the playback heads; (3) that the specified limitation on power consumption would require careful circuit design and would necessitate development of special motors; (4) that the specified limitations on size and weight would necessitate careful attention to layout and packaging details; and (5) that the shock and vibration environments could be troublesome. During the course of the program, additional difficulties arose which, together with those listed above, are discussed in this section.

B. Effects of Thermal Bacteriological Sterilization

It was required that the mechanism and its associated electronics be capable of withstanding approximately 24 hours exposure at 125° C. Electronic components and most mechanical parts in such a mechanism can withstand this environment with no difficulty but it was not known whether the magnetic heads, tape, and Mylar belts could survive. At the beginning, no one advertised heads for use over about 85° C. Data from Ampex and DuPont indicated a safe service life for Mylar of 73 days at 90° C, and 4 days at 125° C (service life being limited to a loss of 1/3 in tensile strength), and indicated that oxide-to-Mylar binding agents deteriorate at temperatures above 55° C. The data state, "Most domestic tape manufacturers specify a safe temperature limit in the order of +70° C."

Initially, we elected to use 3M #1061 or #1132 tape because of dropout considerations. Later, another NASA program developed #LR1220 which we found to be excellent with regard to dropout and flutter characteristics. Our tests on #LR1220 showed no deleterious effects caused by the 125° C exposure other than the usual, initial shrinkage. This type was selected in preference to the others.

In order that the completed recorder assembly survive the brief 125° C exposure, we found it necessary to pre-shrink the tape on a conventional reel prior to assembly in the endless loop magazine; during exposure it is necessary to run the transport to prevent permanent molding of deformations in the tape and belts, and prevent adhesion of adjacent layers. Since the electronics were not designed for operation at such high temperatures, provisions were made to power one motor from an external source. Changing connections after thermal sterilization necessitates chemical sterilization of external surfaces.

S. E. D. Memories (formerly in New Jersey; now in Connecticut) indicated ability to produce high temperature heads within reasonable cost and delivery limitations. Upon receipt, their heads were tested at 125° C and found to be unharmed. A later repetition of the high temperature exposure caused some interlamination bonding agent to evolve. We were ready to reject the heads and request replacement, when, after several temperature cycles, the material ceased to evolve. We found that the head manufacturer had based his confidence on assurances by his bonding agent source that the materials would be perfectly satisfactory. When pressed for an explanation, he found that the bonding agent source had neglected to warn him that "squeeze-out" is a typical phenomenon.

Lately we have been communicating with another source, IMI Magnetics, Glendale, California, who claim considerable experience with extreme temperature problems. We have not yet exposed any of their heads to the sterilization environment, but plan to do so shortly as part of Phase II of the subject contract.

We have some indication that repeated temperature cycling during final evaluation caused degradation of some tantalum capacitors in the playback amplifiers. This may have been aggravated by the thermal sterilization. Unfortunately, we can't be sure without a good deal more testing. However, the possibility has prompted an investigation of the relative merits of chopper amplifiers and direct-coupled amplifier modules in an effort to avoid the tantalum capacitors as much as possible. (In a conventional ac amplifier, large values of capacity are needed because of the low frequency of the playback signals.)

C. Mechanical Problems Associated With Extended Periods of Storage or Inoperation

Extended inoperative periods can give rise to at least two mechanical problems: (1) permanent formation of dents in conventional pressure roller structures and (2) gradual evaporation or oxidation of bearing lubricants.

The first was overcome by a system in which the tape is pressed against the capstans by a Mylar belt rather than by rubber pressure rollers. This technique proved quite successful and probably helped the transport to perform during vibration by helping to maintain contact between the tape and heads.

Although we observed no physical proof, a theoretical study has shown that use of a single pressure belt in a double capstan system can cause tape tracking difficulties. In pressing the tape against the heads, the single pressure belt also could conceivably result in more rapid head or tape wear. Just how much pressure is too much can be determined only by extensive testing. For these reasons we have elected to use two pressure belts, one for each capstan, in future designs. The only apparent deficiency in this two-belt system is the increased possibility of separation between the tape and heads during vibration. It is our opinion that occasional dropouts during vibration must be considered subordinate in importance to poor tape tracking or rapid head and tape wear.

The lubricant problem has no clear-cut solution. As a first step it would appear desirable to replace the all-steel bearings with bearings using vacuum-impregnated phenolic retainers, which can act as oil reservoirs. This certainly can be done in the motors. At the capstans however, indications are that such bearings have measurably greater torque fluctuations which are especially apparent at the low capstan rotational speeds. These torque fluctuations cause flutter. As part of Phase II we are obtaining some assistance from the Barden Corporation which hopefully will result in an answer to whether we dare use the phenolic type in capstan assemblies. The bearing life problem is further complicated by the fact that in areas near the tape and drive belts, notably capstans and idlers, the bearings must contain only film or minimal lubrication. Measurable oil quantities would otherwise eventually migrate from the bearings and cause malfunctioning elsewhere. More significant quantities of oil could be used if the bearings could be sealed, not merely shielded. Seals cause very significant increases in power requirements not commensurate with present power consumption goals.

As far as bearing steel is concerned, an oxidizing atmosphere promotes "healing" of surface damage. On the other hand, such an atmosphere promotes lubricant deterioration. Most qualified advisors recommend an inert atmosphere as the best choice, the latter problem apparently being of greater magnitude.

D. Mechanical Problems Associated With Extended Periods of Operation

Aside from possible, gradual deterioration of electronic components, recorder operating life is limited by bearing life (discussed in the preceding paragraph) and by head and tape wear.

All bearings in the present 10^6 bit machine are all-steel and contain minimal lubrication. The maximum rotational speed is 3000 rpm. At around 2000 rpm it has been recommended that we resort to vacuum-impregnated phenolic retainers and specify some additional oil. In Phase II we are faced with motor rotational speeds reaching 8000 rpm, where, in an inert atmosphere, a bearing life span of 10,000 hours could be achieved by following this recommendation.

In order to operate in an endless loop configuration, the tape must be lubricated. When new tape is placed in operation in such an arrangement, some lubricant rubs off during the first few tape cycles and results in loosening of the loop. If the slack is not taken up, the loop will not wind properly in a horizontal plane or sometimes during vibration. Improper winding can cause creasing or separation of the tape. During initial run-in, burnishing of the oxide surface reduces AM and flutter to a value which remains relatively constant over the life span of the tape. Tape life is affected by many conditions among which environment plays an important part, as suggested by the discussion of sterilization problems. When tape wear becomes significant, the tape begins to abrade the heads, causing rapid mutual deterioration. It is estimated that in this mechanism the tape should survive 5000 cycles at normal temperatures with a dual pressure belt system.

E. Shock and Vibration Environments

In order to operate successfully during mild vibration and to survive severe vibration and shock, it is essential that the transport mechanism be protected by vibration isolators. During the design, we selected more-or-less conventional Lord mounts based upon an accurate estimate of weight. These failed early in the vibration testing. We then fabricated our own mounts in the form of pads (refer to Drawing #B1656-11 for details) which ultimately proved successful. Here, the main problems were to find a suitable agent and technique to bond the rubber portion to its aluminum supports, and to determine physical dimensions which would yield the desired resonant frequencies. It is not yet known whether the assembly would be harmed by chemical bacteriological sterilization or by prolonged exposure to space vacuum. Tests show no problems caused by thermal bacteriological sterilization.

F. Bearing Failures

During the course of this program, an inordinate number of instrument bearing failures occurred in this mechanism and in others being developed or fabricated at REL. Each of the projects concerned joined in a mutual concerted effort to find the cause and solution. Many possibilities arose among which were faulty application, improper handling, and wrong or poor lubrication.

Most of the bearings contained a silicone lubricant which was found to have poorer lubricity than other bases. Its use is indicated only when viscous torque becomes a problem at temperatures below our lower limit of -10° C. The possibility of simply having a poor lubricant clouded the issue somewhat.

In the meantime, calculations and studies showed no faulty designs or poor handling techniques.

Finally, it was found that the bearing steel had been subjected to improper heat treating during manufacture, resulting in dimensional instability. The manufacturer, New Hampshire Ball Bearings, Inc., having determined this to be the problem, replaced all of the particular type supplied to us over a period of several months.

In addition to the time spent in investigation, extra time was spent in rebuilding the transport and its motors and in trying to insure that the new bearings were indeed satisfactory.

G. Power Consumption

In order to achieve the desired power consumption goal, it was necessary to develop motors tailored specifically to the particular mechanism, because the motors use most of the total power. In striving for the best possible efficiency, the motor development took much longer than anticipated. H. C. Roters, who is one of the few qualified sources, was selected to perform this development. He encountered difficulty in achieving the required torque within the estimated power limitations and over the temperature range. The high efficiency gave rise to severe hunting in the record motor which was eliminated by changing the motor drive circuit arrangement.

Our experience in this area indicates that the power consumption goal was not realistic for flight units because of the need for virtual hand tailoring of the motors and the great danger of hunting at high efficiency. Also, addition of more oil in the motor bearings to improve life would increase power consumption considerably. Future specifications should allow some relaxation in efficiency requirements to facilitate manufacture and permit improved life.

H. Low Tape Speed During Playback

The playback tape speed of 0.03 inches per second, dictated by bit rate and packing density, results in a playback head output of less than 100 microvolts peak-to-peak. An amplifier having a voltage gain of roughly 10^5 and a frequency response flat between 5 and 100 cps is needed to recover the signal. Preliminary study eliminated electronic chopper amplifiers because of power consumption. It was felt that a direct-coupled amplifier would be impossible to stabilize over the temperature range. Hence, the remaining alternative, a more-or-less conventional, capacitor-coupled amplifier, appeared to be the only solution. Its design and development was hindered by problems with large-value tantalum capacitors and by its susceptibility to noise generated by the drive system.

It was thought that the very low capstan rotational speed of 3.6 rpm would permit the capstan bearings to introduce significant flutter components due to surface finish irregularities, which are not apparent at higher speeds. Measurements on the breadboard and finished transport showed no significant increase in flutter over higher speed mechanisms.

I. Reconstruction of the NRZ Waveform

The pulses recovered from the tape and amplified to a level suitable for conversion to NRZ show good time stability at the peaks but less stability in slope and position of the rising and falling edges. Literature is supposedly "replete" with suitable peak detection schemes, but none could be made to work satisfactorily in terms of stability without a considerable waste of power. The final scheme uses slope detection in which the pulse changes the state of a flip-flop, better termed a Schmidtt Trigger, about half way up the leading edge. The trigger point drifts somewhat depending upon the slope of the individual pulses, but the resulting signal jitter is well within the limits beyond which the subsequent shift register would fail.

J. Electrical Noise

As mentioned in paragraph H, completion of the playback amplifiers was hindered by noise problems. Noise is generated internally by the square wave motor power system. The initial design included complete shielding for the playback amplifiers and motor power amplifiers, but common power supply leads and ground returns were found to be of great significance in the completed assembly. Considerable revision of dc power distribution connections and ground returns was needed to keep this motor noise out of the amplifiers.

Motor noise picked up by the playback head was present but not of great enough magnitude to cause trouble. External noise, primarily 60 cps, did however, enter the system through the playback head whenever the unit was placed in a temperature chamber for tests. This noise was reduced to tolerable levels by careful orientation of the mechanism and by shutting off the chamber power while obtaining data.

The encoder-simulator was supplied from relatively simple dc sources, rectified from the 60 cps ac line.

During dropout testing, it was found that line transients caused frequent malfunctions in the encoder. These at first gave the impression that the recorder itself had a significant error rate. It was necessary to remove the recorder and all associated test gear to an area where line transients could be minimized in order to perform a meaningful dropout test.

K. Phase-Locked Loop Tape Speed Control

A preliminary transform analysis of the proposed servo loop uncovered an inherent instability which could be avoided only if the motor were heavily damped or were an induction type instead of a synchronous type, or if significant damping were purposely introduced by means of some device such as a viscous-coupled inertial damper. A discussion with an authority who had attempted similar control of a more conventional or commercial mechanism verified our conclusion.

To achieve proper synchronism it is necessary to compare the relative phase of two signals, one the reference and the other from the tape, each having a rate of roughly 1 cps. The result of the comparison is used to control the frequency of a 400 cps voltage-controlled oscillator. Any 1 cps ripple in the phase comparator output will cause 1 cps frequency modulation of the oscillator frequency. Removing the 1 cps ripple by conventional filtering techniques is simply not practical.

The two problems, instability and filtering, ultimately resulted in development of the gated integrator mechanism which avoids both problems and provides adequate speed synchronism.

L. Container Sealing

Tests on sample covers with Gask-O-Seals showed leakage rates higher than advertised and the possibility of a large, transient leak somewhere during the various environmental conditions. Further study was conducted to check the measured rate and to find whether the transient leak would recur.

We found that the measured value was indeed greater than Parker's claimed value; they have since revised their specifications. The higher rates appear adequate for roughly one year in space vacuum. Since other REL programs did not uncover evidence of transient leaks, and since seals for flight hardware would undoubtedly be made with new molds and would therefore need re-evaluation, we elected not to pursue the transient investigation.

V MECHANICAL DESCRIPTION

(Refer to Drawings #1656-1, -2, and -110)

A. Chassis

The entire mechanism is mounted on a rectangular cast magnesium chassis 7.125 x 6.125 x 0.750 inches. The 15-pin connectors are recessed in one 6.125 x 0.750

inch surface. A purging and filling valve is mounted on the opposite surface. Vibration isolators attach to two 7.125 x 0.750 inch surfaces. One side of the chassis supports the tape reel assembly, heads, and a circuit board with power control relays. The rear of the chassis supports the various drive mechanism assemblies and three electronic boards.

B. Covers

Two covers, each containing an integrally molded Viton Gask-O-Seal, attach directly to the chassis. One is 7.125 x 6.125 x 2.437 inches; the other is 7.125 x 6.125 x 1.125 inches; the deep one covers the rear and the shallow one covers the front of the chassis. The Gask-O-Seals plus potting behind the connectors effect a hermetic seal to maintain atmospheric pressure within the assembly. Loss of pressure would cause rapid evaporation of lubricants and possibly other effects leading to early failure.

C. Capstan Mechanism

The tape is driven by two capstans having a constant of 1/2 inch linear motion per revolution. The downstream capstan turns at 1% - 3% faster than the upstream capstan so that slipping between the tape and one or the other capstan occurs to produce the required tape tension in the head area and at the same time to prevent irregular tape motion within the reel from causing flutter and amplitude modulation. For reasons given earlier, pressure between the tape and capstans is maintained by a Mylar belt rather than by conventional pressure rollers. The two capstans are coupled by a belt running between a pulley on each. The pulleys have a slight difference in diameters to produce the speed differential. At the rear of each capstan is an overrunning, wrap-around wire spring clutch, each having a drive pulley. The clutches are arranged so that whichever is driven faster will lock and drive the capstans while the other overruns.

D. Drive Systems

Two motors are used, one for high tape speed (3.6 IPS) during record, and the other for low tape speed (0.03 IPS) during playback. Use of a separate, low-power motor for playback provides a power saving of roughly 1/2 watt. The playback motor is coupled to the downstream capstan clutch pulley via a three-step speed reduction; the record motor is coupled to the upstream capstan with a single speed reduction. In each case mechanical power is transmitted by Mylar belts. The high speed drive belt also operates a timer mechanism whenever the record motor is running. The timer shuts off the mechanism after 1000 seconds of recording. The capstans, idlers, and motors are mounted as modules so that they can be removed as individual units for test purposes. Each shaft is eccentric from its housing retaining screw circle so that by rotating the modules, adjustments in belt tensions can be made.

E. Tape Reel

The endless tape loop, 300 feet of 1/4" 3M #LR1220 tape, is housed within a 3-1/2" diameter enclosed reel. The loop pack revolves on a bearing-mounted central hub in the form of a right conical section from which the tape is pulled. Withdrawing tape from the inside causes rotation of the pack so that tape will wind on the outside. Since one reel flange, in this case the rear flange, must have a cut out area through which the tape can be pulled, it cannot rotate. This flange is provided with several rollers having their axes along diameters of the flange. These provide bearing surfaces for one side of the tape pack. The other flange rotates with the hub and pack.

F. Heads

Individual record and playback heads are mounted between the capstans and placed so that the tape crosses the record head first. Two heads simplify switching and permit optimizing the playback head, whose high inductance makes it unsuitable for recording. Three-track heads were purchased because of the possible need for a separate bit sync track, later found unnecessary. Future models could utilize two-track heads and with greater track width achieve greater signal amplitude during playback. Head specifications are listed on Drawings number A1656-42 and A1656-43.

G. Thermistor

A small disc thermistor, encapsulated in a housing that is mounted in a recess in the chassis beneath the reel, provides a means for monitoring chassis temperature during thermal testing.

H. Electronics

All of the electronics except control relays are wired on three cards supported by posts on the rear of the main chassis. The first card, which is located in a recess opposite to the reel, contains mainly special circuits associated with the speed control system. The next, enclosed in a two-piece shield can, contains the high-gain playback amplifiers. The outermost card contains the motor circuits in a two-piece shield can and the digital logic modules. Each card is provided with a connector to facilitate removal.

VI ELECTRICAL DESCRIPTION

(Refer to Drawings #1656-16 through 1656-28)

A. Controls

The three modes, Record-Playback-Off, are controlled by four magnetic latching relays which control distribution of the ± 20 VDC and ± 6 VDC external power to the appropriate circuits. Brief pulses are required to actuate the relays. JPL elected to have the circuit arranged so that it would be necessary to switch to OFF before changing between the two operating modes. During recording, +20 VDC is applied to a capacitor through a resistor. When the timer switch closes after 1000 seconds of recording, the capacitor is discharged through the relay coils in such a way as to cause switching to OFF.

B. Record Circuits

Record circuits consist of two channels, one for NRZ data and one for word sync information. Each track requires a push-pull signal to drive its record head which can be derived from standard flip-flops. It was intended to drive the heads directly from flip-flops, but it was found that the magnitude of record current needed and effects of head inductance made this impractical. At the time when the circuit as it now appears was selected, it was more expedient to add buffer stages between the flip-flops and the heads. The system in the data channel could be replaced by a simple push-pull amplifier in a redesign. There are several ways of using the available word sync pulses to achieve synchronism during playback, all of which result in about the same amount of logic functions. During recording it is necessary to stretch the incoming word sync pulse to at least one full bit period as accomplished by the nand circuitry and flip-flop in the word sync record channel.

C. Playback Circuits

Two high-gain, capacitor-coupled amplifiers are used to recover the reproduced signals. The data-track amplifier delivers positive- and negative-going pulses, one polarity representing a "1" and the other a "0". These are converted to NRZ with attendant transport jitter in the following flip-flop or Schmidtt Trigger. The sync-track amplifier is biased so that only negative-going pulses are delivered to trigger the delay flip-flop (one-shot). Reasons for using capacitor-coupled amplifiers have been given in an earlier section. At the expense of additional logic circuitry in the record circuits, both playback amplifiers could be identical including replacement of the delay flip-flop with a trigger circuit identical to the one in the data track which reconstructs the NRZ waveform. However, temperature stabilizing of these playback circuits is considerably more difficult than stabilizing those presently used in the sync track system.

During evaluation of the complete assembly, modifications in the amplifiers to effect temperature stability and reduce noise susceptibility changed the bandpass characteristics so that frequency response data was no longer accurate. Therefore these data are not included in the performance section.

A shift register, pulsed by an externally generated bit sync, removes jitter from the data so that when phase lock is achieved, data output is absolutely synchronous and jitter-free. The one-half bit delay between the shift register input and its shift pulse is a natural result of phase relationships in the phase-locked loop control system.

D. Phase-Locked Loop Tape Speed Control

Reasons for using the gated integrator technique have been given in an earlier section. Refer to Drawings #1656-16, -27, and -28 for circuit details, and to Figures 1, 2, and 3 in the Appendix for waveform relationships.

During playback, the leading edge of the external word sync pulse turns on the integrator reset gate and causes a current pulse to be drawn from the integrator input. The magnitude of this pulse is such that within 1 - 2 milliseconds, the integrator output voltage rises to a level of +15, at which point the stop gate delivers a pulse that shuts off the reset gate. Then if the delay flip-flop output is +6 V rather than 0 V, the integrate gate delivers a constant current input to the integrator causing its voltage to fall at a rate of 10 volts per 120 milliseconds, stopping and holding when either the stretched word sync pulse or delay flip-flop signal drops to zero. The lower limit is +5 VDC. Ordinarily the two controlling signals overlap by 60 milliseconds, one-half a bit period, so that the integrator output voltage averages +10 VDC and the VCO frequency averages 400 cps, the nominal center value.

If the pulse from the recorder sync track occurs late, integration persists longer, and the integrator output voltage averages less than +10 VDC. The VCO which controls playback motor and tape speed then runs faster so that the next sync pulse from the tape will occur earlier. Thus the tape speed (and hence playback frequency) is varied according to the relative phase angle between the external word sync and the sync extracted from the tape. Note that the nominal phase displacement is one-half a bit period so that the output shift register, flip-flop 5, is automatically shifted at the proper time.

If both pulses which are compared in phase have the same duration, a plot of the over-all control characteristics versus relative phase angle will show two immediately adjacent areas, one representing a negative feedback and the other a positive feedback condition. As the phase changes rapidly during lock-in, this condition will cause overshooting and general difficulty in achieving lock. If however, these positive and negative feedback areas are separated by lengthening one pulse or the other, phase lock is achieved in the least amount of time. Ideally, one of the signals should have a 50% duty cycle, provided in this case by the delay flip-flop.

E. Motor Amplifiers

It was intended that both drive systems be two-phase, because this configuration is not particularly sensitive to temperature induced impedance variations which usually cause problems in single-phase capacitor systems. The frequency variations in the playback drive system just about rule out a single-phase capacitor system for this drive.

However, during development it was found that the record motor hunted severely when operated as a two-phase motor, while the playback motor did not. The success of one and failure of the other was attributed to different magnetic characteristics in the respective rotors. It was found that the record motor was stable when operated as a single-phase capacitor motor, for which no conclusive explanation can be offered.

Note that the schematics call for certain selected capacitors. These values are quite critical, small variations causing significant changes in available torque because of the marginal design. Some increase in battery power must be allowed to make these drives practical to build and provide a little more available shaft power.

VII PERFORMANCE DATA AND OTHER PARAMETERS

A. Bit Capacity and Bit Rates

The specifications require a capacity of 10^6 bits, an input rate of 1000 bits per second, and an output rate of 8-1/3 bits per second. The ratio between the two rates is 120. These requirements were fulfilled by using a single data track at a linear packing density of 278 bits per inch, which is a conservative value. Record tape speed is 3.6 inches per second and playback tape speed is 0.03 inches per second. A greater packing density, which ordinarily would cause no problems and would result in less tape or greater capacity, in this case would cause significant difficulties because of reduced playback tape speed. Total capacity of 10^6 bits results in a tape length of 300 feet. The existing reel housing has space for an estimated 5% - 10% additional tape. The existing chassis could accommodate an even larger reel if the relay assembly were placed elsewhere. With a capacity of 10^6 bits and rates of 1000 and 8-1/3 bits per second, record time is 1000 seconds or 16-2/3 minutes and playback time is 120 times longer or 33-1/3 hours.

B. Error Rate

An error rate not exceeding one bit out of 10^5 bits was specified. Because of noise introduced when the assembly was placed in an environmental chamber and introduced by the magnetic field of the vibration test device, an actual dropout count could be performed only under room conditions. Susceptibility of the encoder-simulator to ac line transients could be avoided cnly by testing with as few cyclic devices connected to the ac line as possible. Under these more-or-less ideal conditions, a careful recording was made and played back. During playback, recorder output is synchronous with data generated by the encoder-simulator. These two data signals were compared bit-by-bit by means of the logic circuitry shown in Figure #4 which pulsed a decade counter each time individual bits were not identical. The resultant count shows the sum of recorder and simulator errors, the latter being rather numerous until the ac power source was improved by removing causes of transient loading.

The first 20 hours of the 33 hour recording was searched twice, the first time yielding 2 errors, and the second time some 5 days later, 3 errors, in each case less than the allowed maximum.

Separate checks were made in the vicinity of the tape splice, which in one case caused 8 errors and later 13 errors. These apparently resulted from a brief loss of phase lock, possibly due to an error on the sync track. It should be pointed out that if an error occurs on the sync track, temporary loss of lock will mean the loss of one or more words.

C. Input Impedance

Input inpedance was required to be greater than 10 K. This was provided by means of a 10 K input series resistor.

D. Output Impedance

Output impedance was required to be less than 1 K. This was provided by means of an output emitter follower having an ac output impedance of 300 ohms, measured under nominal conditions.

E. Input Voltage

It was required that the recorder be capable of recording NRZ data having an amplitude between 1 and 6 volts, zero-to-peak. This was achieved by a simple, single-stage voltage amplifier preceding the data recording logic circuits, which nominally require 6 volt signals.

F. Output Voltage

NRZ output was required to have an amplitude of at least 1 volt, zero-to-peak. This signal is derived from a flip-flop which at minimum supply voltage delivers about 5 volts, zero-to-peak. Roughly 0.5 volts is lost in the

NRZ output amplifier (emitter follower) resulting in a no-load output greater than 4 volts, zero-to-peak, at minimum supply voltage.

G. Record Mode Start-Stop Time

It was required that the transport be capable of starting and stopping in the record mode within 5 seconds. (Poorest acceleration occurs under reduced-temperature, reduced-voltage conditions.) To measure this parameter, a signal at approximately 3 Kc was recorded on the complete loop at 3.6 IPS. The playback head and a line carrying dc whenever the record motor was powered were connected to two respective channels of a Visicorder. The amplitude of pen displacement caused by the reproduced signal at 3.6 IPS was indicative of relative tape speed. Displacement of the other pen indicated the time at which motor power was applied and removed. A typical chart is reproduced in Figure #5, showing start and stop times of 0.63 and 0.48 seconds respectively at -10° C and minimum voltage.

H. Flutter

Maximum total flutter content was specified as 1% peak-to-peak with no limitation on bandwidth. For a machine of this type, flutter in the order of 1% peak-to-peak is indicative of good over-all mechanical quality. In an FM machine, flutter is of paramount interest because it contributes directly to additional and unwanted frequency modulation. In a digital machine, however, jitter (variations in time between recorded events) is of more concern. In this case, flutter measurements provide basic information relative to quality of mechanical components; but without knowledge of the flutter spectrum, the data are difficult to relate to jitter. The maximum possible per cent time displacement error is the sum of the peak instantaneous per cent speed deviations during recording and reproduction, and will be achieved only when the time between events is a negligible fraction of the flutter period (assuming sinusoidal flutter). Further discussion of jitter is given in paragraph I.

Measurement of flutter requires that the machine reproduce a signal output at several thousand cycles per second for practical frequency demodulation by a subcarrier discriminator. The output of the discriminator, indicating instantaneous speed deviation, is generally plotted by means of a Visicorder so that individual sources of flutter may be determined from their respective repetition rates coupled with a knowledge of the various rotational speeds.

Flutter measurements on this machine were extremely time-consuming because of the very low playback tape speed. In order to obtain a suitable signal for the discriminator, it was necessary to record a 25 cps signal at 0.03 IPS. When played back at 3.6 IPS, this resulted in a reproduced output at 3000 cps. Under these restrictions, to obtain a 10 minute playback required a 20 hour recording. Since flutter must be checked under various combinations of temperature, voltage, transport orientation, etc., a good deal of time was required to complete the evaluation.

The discriminator output was bandlimited to 330 cps, and with this restriction, measured values of flutter approached but did not exceed 1% peak-to-peak. No significant changes were noted as a function of temperature, voltage or orientation. A typical chart is reproduced in Figure #6.

I. Phase-Locked Loop Performance

The phase-locked loop tape speed control, assisted by the output shift register, achieved perfectly synchronous NRZ output. After the playback amplifiers stabilized following application of power, the loop always achieved lock within passage of 10 words. A detailed re-evaluation of the system dynamics might indicate minor revisions in loop gain or loop equalizing which could hasten lock-in. However, such improvements could be rendered ineffective by temperature-induced changes in motor torque and motor load. The existing system was considered adequate for its purpose.

Following lock-in, steady-state and transient phase errors or jitter are of primary concern.

The VCO center frequency was set so that steady-state phase error was zero (90° shift between the two inputs to the phase comparator) under nominal room conditions.

After this adjustment, steady-state phase error can be caused by drift in the integrator reset voltage limit, the integrator time constant, the VCO frequency control-voltage curve, movement of the playback head in azimuth, stretching of the tape, and slipping of the tape or belts.

The integrator characteristics were found to be stable. A curve of VCO frequency versus control voltage as a function of temperature, Figure #7, shows that at nominal clock frequency, a VCO center frequency shift of 1% occurs over the temperature range. This will cause a steady state time displacement of 1/10 the maximum allowable value of 60 milliseconds because the loop gain is such that a 60 millisecond error results in a 10% frequency shift. During a later study of system performance, a time displacement corresponding to ±1.7% shift in center frequency over the temperature range was noted. This may be attributed to changes in the VCO when it was repackaged combined with possible, unobserved variations in the integrator.

A signal representing 1-0-1-0-1-0-1 was recorded and played back under various combinations of temperature extremes. The initial phase adjustment made under room conditions was left undisturbed. During playback of each of these recordings, the reproduced NRZ ahead of the shift register (with jitter) was compared bit-by-bit with the shift register or equivalent encoder-simulator output (jitter-free) by means of an oscilloscope.

Since a bit has a duration of 120 milliseconds, the initial adjustment provides a 60 millisecond delay between the two waveforms. Bit-by-bit comparison showed each wavefront to jitter by ±10 milliseconds generally, occasionally reaching ±20 milliseconds near the beginning of a word where speed changes are most rapid as a correction occurs. Most of this average jitter is attributed to variations in slope and amplitude between individual reproduced pulses, which cause variations in trigger-time of the NRZ flip-flop.

At the temperature extremes, no change in average jitter was observed. However, the average phase advanced and retarded as a function of temperature, an amount corresponding to a ±1.7% shift in VCO center frequency as noted previously. Theoretically, lock can be maintained until the frequency shift exceeds ±10%. If the shift approaches ±10%, initial phase-lock is difficult to achieve. Note that the greater the loop gain (VCO deviation in cps per radian phase change or per millisecond time shift) the greater is the cumulative drift that can be accommodated by the loop, until the stability criteria are exceeded.

J. Power Consumption

A goal of a maximum power consumption of 500 milliwatts was specified at room temperature and nominal voltage. Measured values were 665 milliwatts in record mode and 425 milliwatts in playback mode, distributed as follows:

Source	Current	
	Record	Playback
+6 VDC	10 ma	20 ma
-6 VDC	<1 ma	4 ma
+20 VDC	30 ma	12 ma
-20 VDC	<1 ma	2 ma

Most of the power in each case is required by the respective motors. Refer to the Appendix for complete motor data.

A considerable effort was made to achieve best possible motor efficiency, which caused hunting problems and required selection of motor amplifier components. To make these drives practical in terms of cost and delivery, some relaxation in efficiency must be allowed. Additional bearing lubrication and still more power is required to insure an operating life of one year.

K. Weight

Preliminary estimates resulted in a weight goal of 5 pounds. The completed machine weighed 7.77 pounds distributed as follows:

Shallow Cover	0.638	pounds
Deep Cover	0.887	pounds
Cover Hardware	0.156	pounds
Chassis with transport and electronics	6.08	pounds
Total	7.77	pounds

L. Size

A goal of 100 cubic inches was established for size. The volume of the complete assembly, except the vibration isolators, is 155.2 cubic inches, distributed as follows:

Chassis plus cover flanges	54.5 $in.^3$
Shallow cover less flange	28.9
Deep cover less flange	71.8
Total	155.2 $in.^3$

A saving of 30 - 50 cubic inches can be achieved by modular packaging of the electronics, which was beyond the scope of this effort.

The two vibration isolators occupy a little less than 10 cubic inches.

VIII EFFECTS OF ENVIRONMENT

A. General

Tests involving transportation environments, humidity, vacuum, shock, and radio interference were deleted by mutual agreement.

B. Sterilization Temperature

Exposure at 125° C for 24 hours requires that the tape be preshrunk while loosely wound before it is installed in the recorder. The recorder must be operated to prevent molding permanent deformations and to prevent adhesion of adjacent layers of tape. With these precautions, there should be no deleterious effects.

(We have been assured that the head trouble will not recur on future units.)

C. Space Flight Temperature

The present assembly performs over the temperature range from -10° C to +75° C. Beyond the lower limit, the record motor torque becomes marginal so that any latent mechanical defect may result in drive failure. Beyond the upper limit, gain changes in the playback amplifiers cause increased susceptibility to noise and errors in data output. Design improvements for flight units can eliminate these difficulties and extend the range somewhat.

D. Vibration

By mutual agreement, sinusoidal vibration was substituted for white noise. The recorder was protected by isolators which are essential for the frequency spectrum and acceleration levels involved. Each of three mutually perpendicular axes were subjected to accelerations up to 10 g rms in the frequency range from 5 to 2000 cps. During these tests, the recorder assembly was observed physically for defects and electrically for proper functioning. Accelerometers were used to determine the resonance and transmissibility of the suspension, one being mounted on the recorder chassis and another on the vibration table.

Resonant frequencies and transmissibilities of the isolators are shown in Figures #8, 9, and 10. Note that variations occur depending upon orientation. Data obtained with other samples indicates some variation in resonance and transmissibility as a function of acceleration level, probably due to the non-linear modulus of the material and differences between static and dynamic moduli. Curves for the final mounts were obtained at 10 g rms input and show, in the worst cases, a resonance of 180 cps and a transmissibility of 3.4.

With the shafts horizontal and vibration parallel to the long dimension of the mounts (machine upright on table), the following phenomena were observed.

At 3 g rms between 7 and 30 cps the sync track delivered a signal frequency equal to the vibration frequency indicating a physically induced malfunction such as short circuiting due to shield displacement or open circuiting at a connector. Aside from loss of lock, the data track functioned properly.

At 6 g rms the same trouble with the sync track occurred. Between 450 and 600 cps the reel flange and hub tended to rotate backwards during playback although the tape itself wound and paid out satisfactorily. Also in this range, the timer pulley tended to rotate. The timer belt wrap should be increased and some small drag should be built into the timer to prevent this. As long as the data track functioned, it could be assumed that recording would be normal.

With the shafts horizontal and vibration compressing the mounts, the same phenomena were observed. Mechanical noise indicated some relative motion of the electronic cards or their shield enclosures. A complete, new recording was made during vibration at 6 g rms with the vibration sweep rate set for a 15 minute period between 5 and 2000 cps. With no vibration, the entire recording was scanned in search of defective areas. No indication of any poor areas was found.

Nothing of significance occurred when vibration was applied along the axis of the shafts until a level of 10 g rms was reached. At this point, the playback drive ceased to operate. The record drive and electronics continued to function. Examination of the mechanism showed that a power lead on the relay board had broken. Repair restored normal operation. The particular wire and several others in the immediate area had previously been subjected to a good deal of abuse during the overhaul which included bearing replacement and timer revisions. Ordinarily point-to-point leads would be bonded in place to minimize danger of breakage. In this mechanism, areas were not bonded where there remained a possibility of wiring revisions.

Following the repair, the assembly was checked for any degradation in performance. Power input indicated no changes in motor load or performance. No increase in jitter was detected. It was noted that the steady-state phase error had changed by 10 - 20 milliseconds. Tests revealed that the VCO center frequency had shifted, most likely because of a change in a potentiometer suspected of being unstable. Direct comparison of the two playback amplifier output signals showed that one head, undoubtedly the playback head, had moved approximately 0.0005 inches in relative gap positions, also contributing to a change in steady-state phase error. This has not been observed on other machines and could be attributed to poor locking of the head adjustment. A coplanar block assembly, although more expensive, eliminates the need for azimuth adjustment.

E. Static Acceleration

The assembly was subjected to static acceleration of 14 g along each of three axes, two along the shafts and one at right angles to the shafts. At the conclusion, a bench test showed no degradation in performance.

IX DESIGN IMPROVEMENTS FOR FUTURE UNITS

A. General

Experience gained during evaluation indicates certain areas where improvements can and should be made if the particular design is intended for flight use. Possibilities for improvement have been demonstrated by other current programs as well.

B. Electrical

Recent studies have shown that it is possible to obtain significantly increased output from the playback head. Employing these newer heads, possibly combined with the record head in a single coplanar block, and improving the playback amplifier gain stability and reducing its noise susceptibility would result in a more reliable system and less need for selected amplifier components.

Certain wiring changes are essential. Power and ground leads should be revised to reduce coupling of noise from the motor circuits to the playback circuits. Cable routing should permit easier access to the heads directly to facilitate adjustments and flutter tests. Grouping all of the logic modules on a single card resulted in the need for a 44 pin connector on the card. A number of reasons developed for avoiding such a multiplicity of termination in a single connector. Testing was hindered somewhat by the control system. It should permit high speed operation without tape erasure and should provide an override on the timer.

Needless to say, resorting to encapsulated modular assemblies with welded interconnections would afford a substantial improvement in reliability and a reduction in size.

C. Mechanical

Both motors should use bearings having vacuum-impregnated phenolic retainers to extend their life. The record motor torque must be increased to provide a better safety margin at low temperature. More motor power input must be allowed to accommodate additional lubricant, provide greater torque, and facilitate manufacture.

Means must be provided which prevent the timer from rotating of its own accord during vibration.

The upstream tape guide should be moved as close to its capstan as possible. The downstream capstan should be moved away from its capstan or possibly eliminated. These changes have been shown to improve tape tracking.

The single pressure belt should be replaced by two, one for each capstan, to improve tape tracking and reduce the possibility of head wear.

Rollers in the tape magazine should be lengthened to improve uniformity of tape motion within the reel housing.

The external connectors should be sealed with Gask-O-Seals as well as by potting, to reduce leakage.

A pressure transducer should be included to insure that the seals do not permit large transient leaks that cannot be detected by periodic checks of leakage rate.

Since the effects of prolonged exposure to vacuum on the vibration isolator material and its bonding agent are unknown, the ultimate means for mounting should restrain the assembly if the isolators fail.

X NEXT PHASE

Immediate steps are being taken to apply welded modular techniques to the present electronic circuits. Experience gained in this exercise will be extremely valuable when assembly of flight-worthy units is begun.

A new development is underway to extend the present design to multiple data rates and a ten-fold increase in storage capacity. This new system requires synchronous playback at significantly higher rates. The completed assemblies will incorporate the improvements noted previously and will utilize welded, modular electronic subassemblies separate from the transport mechanism.

F. A. Stone:rw

APPENDIX

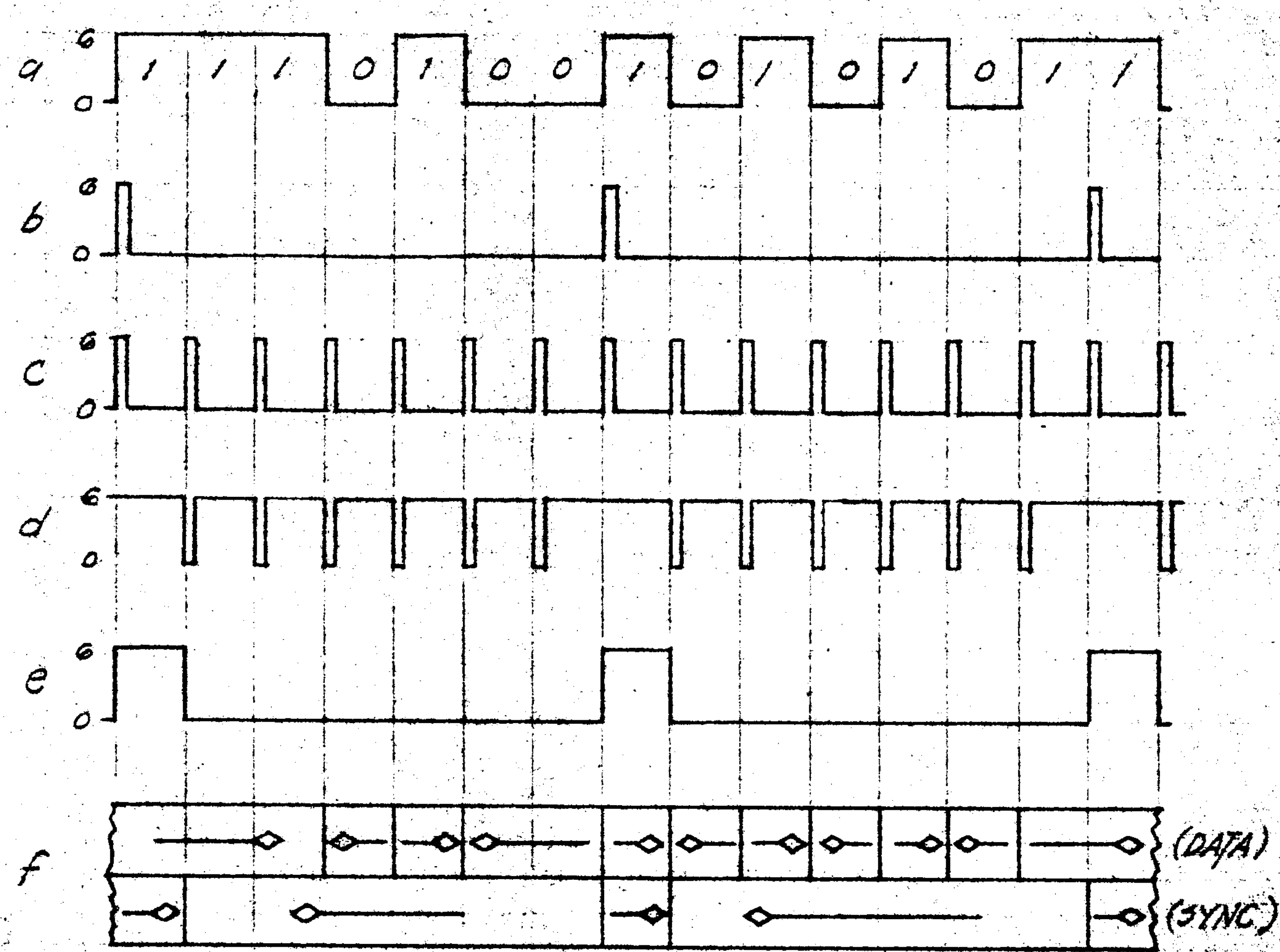


FIGURE 1

WAVEFORM RELATIONSHIPS DURING RECORDING

a. NRZ INPUT & RESULTING DATA TRACK RECORD HEAD CURRENT.

b. WORD SYNC INPUT.

c. BIT SYNC INPUT.

d. RESET PULSES APPLIED TO FLIP-FLOP 2.

e. FLIP-FLOP 2 OUTPUT & RESULTING SYNC TRACK RECORD HEAD CURRENT.

f. RELATIVE DIRECTIONS OF TAPE MAGNETIZATION.

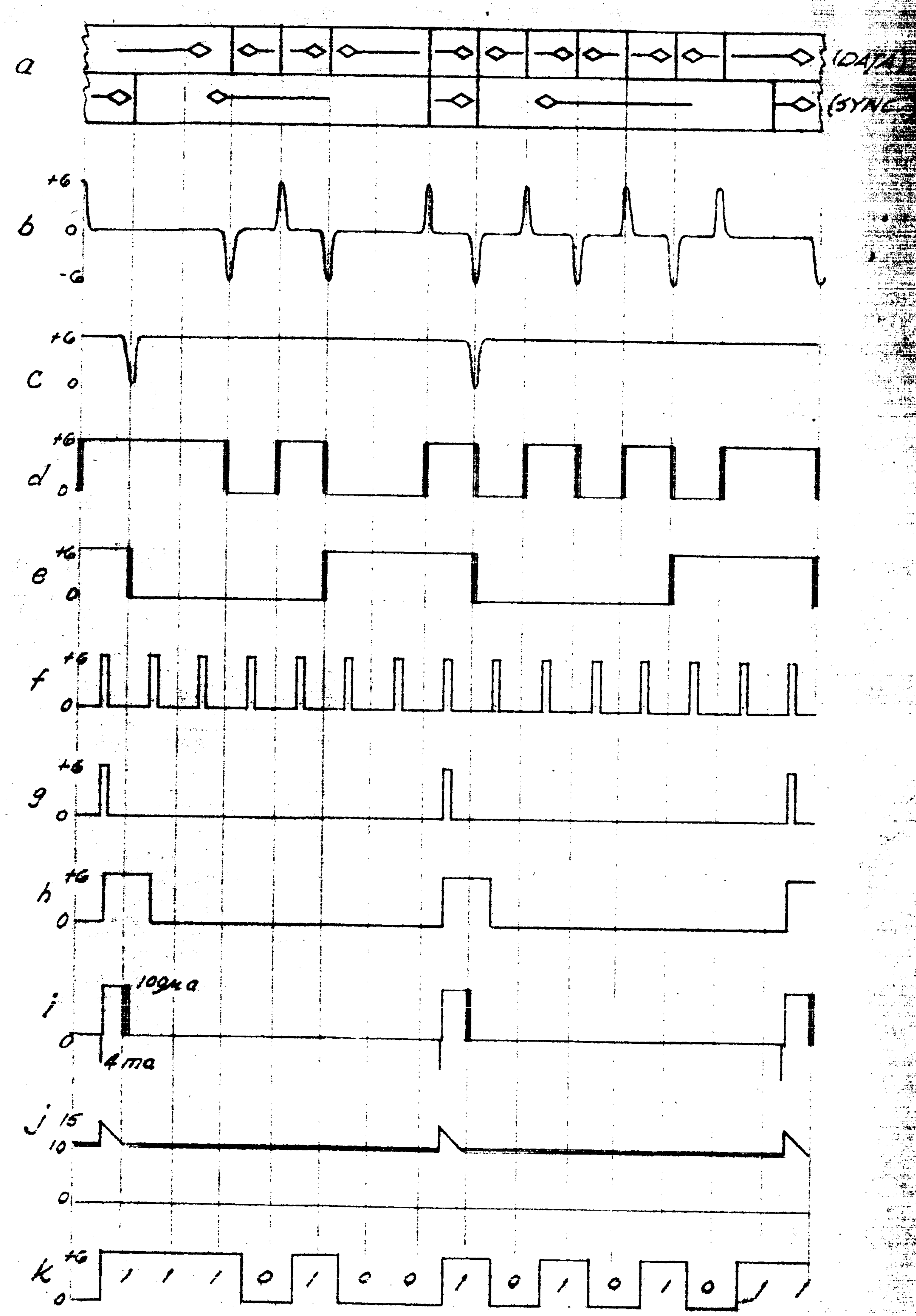


FIGURE 2

WAVEFORM RELATIONSHIPS DURING PLAYBACK

NOTE:

HEAVIEST LINES DENOTE TIME OR VOLTAGE MAGNITUDE VARIATIONS RESULTING FROM TRANSPORT JITTER.

a. PATTERN OF RECORDED SIGNALS.
b. OUTPUT OF PULSE AMPLIFIER 1.
c. OUTPUT OF PULSE AMPLIFIER 2.
d. OUTPUT OF N.R.Z FLIP-FLOP.
e. OUTPUT OF DELAY FLIP-FLOP.
f. BIT SYNC INPUT.
g. WORD SYNC INPUT.
h. OUTPUT OF FLIP-FLOP 9.
i. CURRENT INPUT TO INTEGRATOR.
j. VOLTAGE OUTPUT FROM INTEGRATOR.
k. NRZ DATA OUTPUT FROM FLIP-FLOP 5 (SHIFT REGISTER).

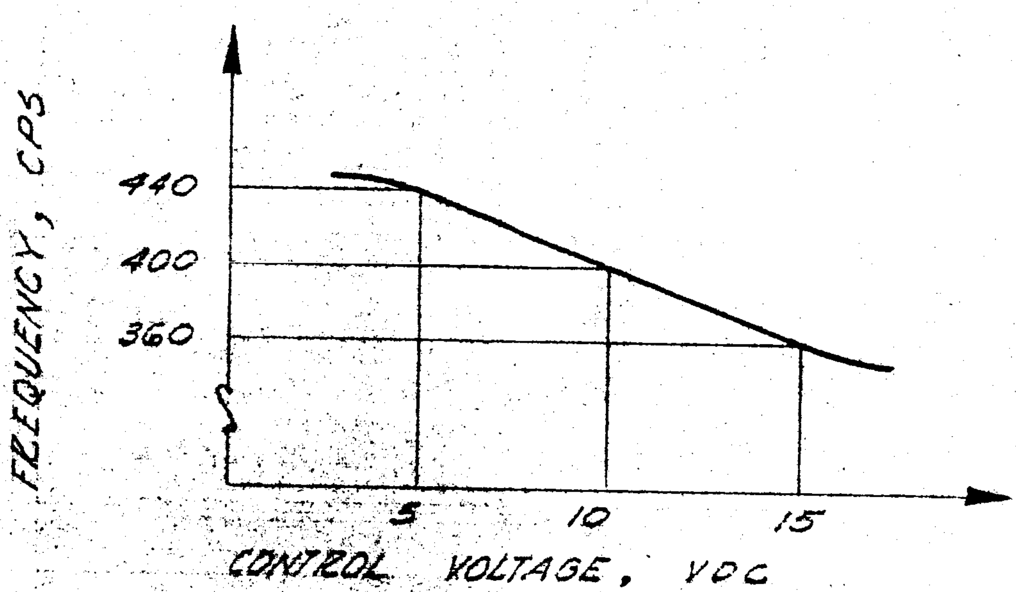


FIGURE 3

VCO FREQUENCY-VOLTAGE CHARACTERISTIC

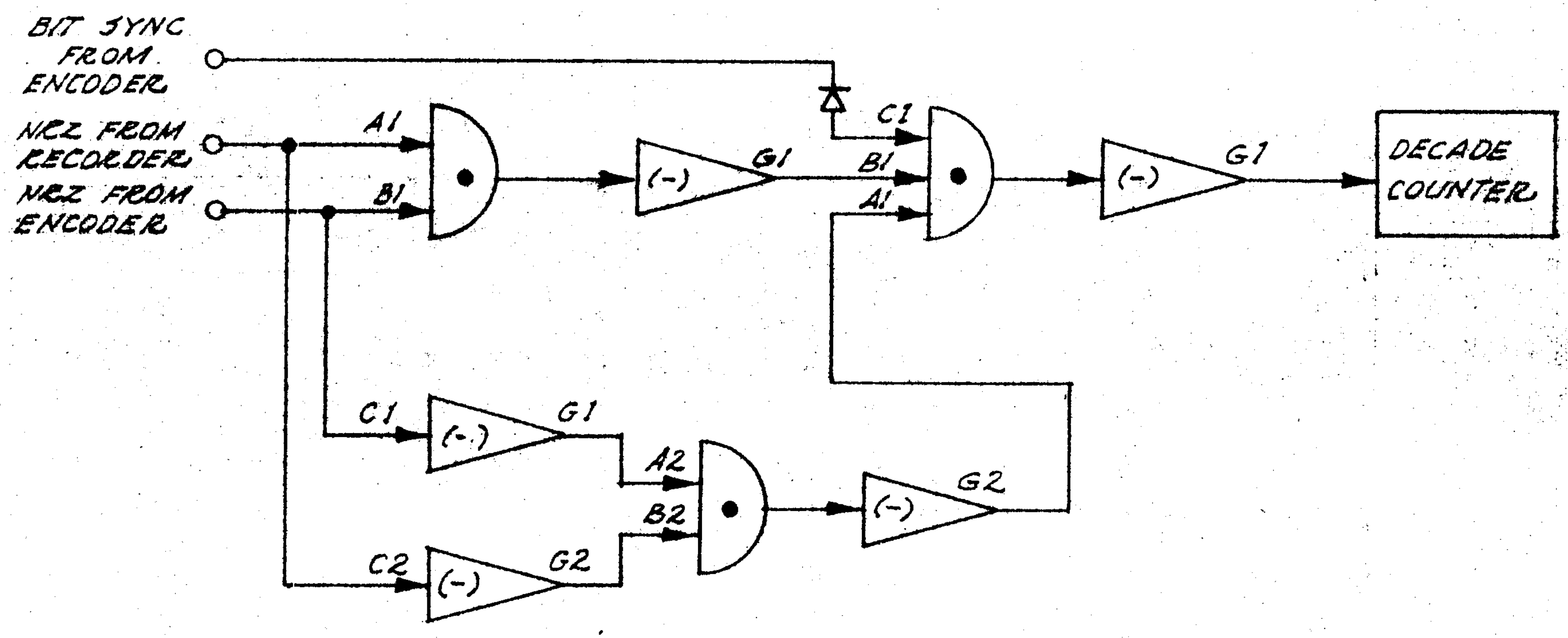


FIGURE 4

DROPOUT DETECTOR & COUNTER

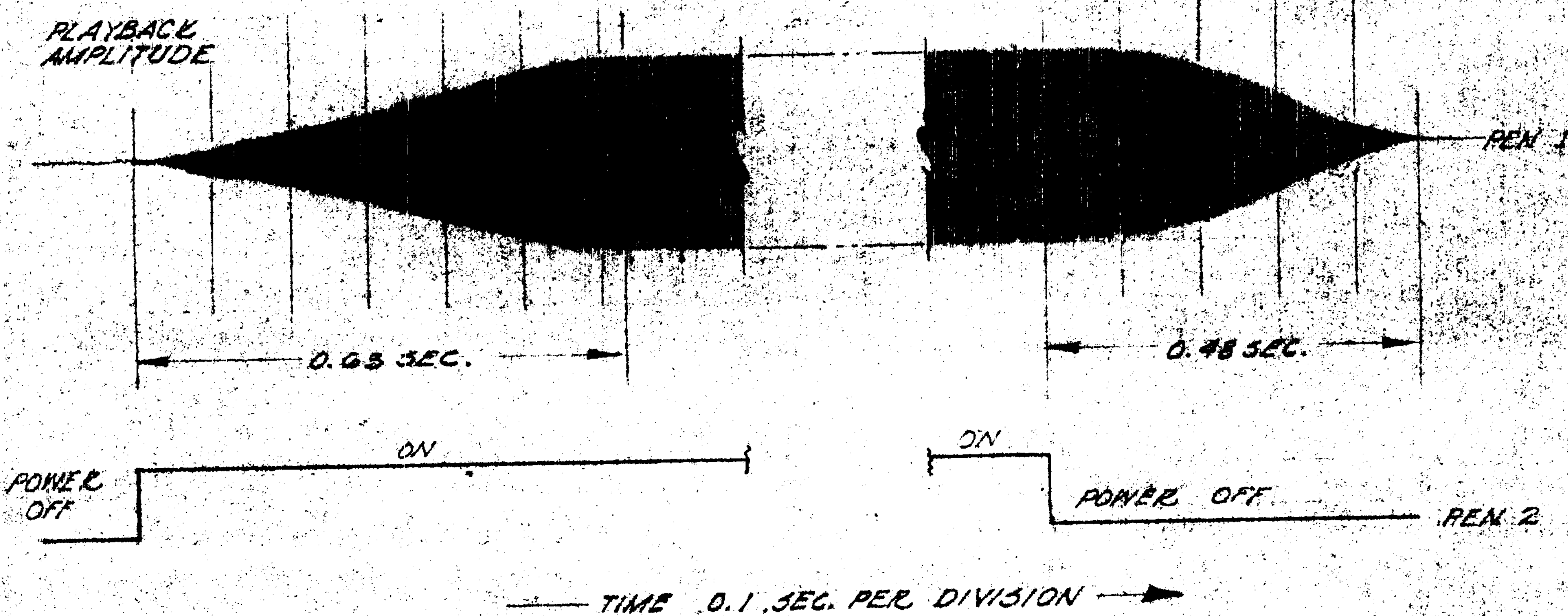
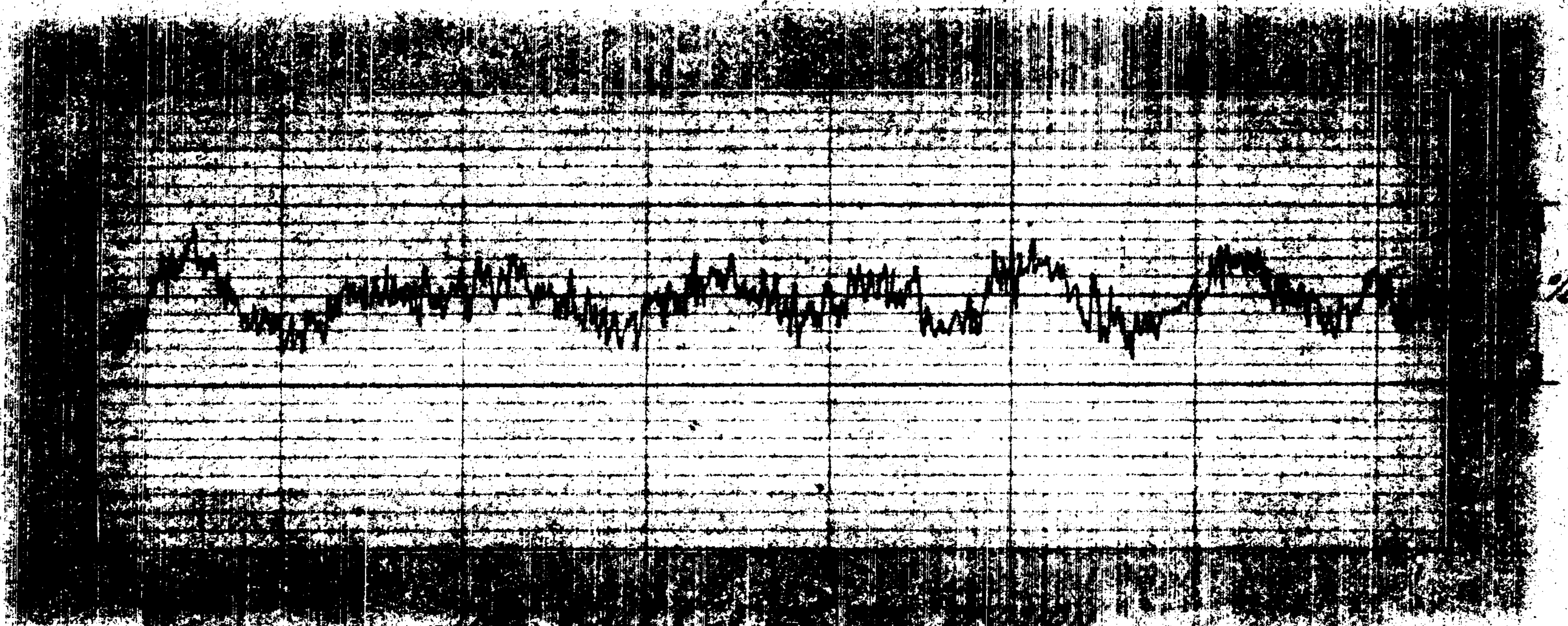


FIGURE 5

CHART SHOWING MEASUREMENT OF TRANSPORT ACCELERATION TIME



FREQUENCY SCALE: .1% DEVIATION PER DIVISION

FIGURE 6

TYPICAL FLUTTER CHART

CONTROL VOLTS	IDEAL FREQUENCY
5 VDC	440 CPS
10 VDC	400 CPS
15 VDC	360 CPS

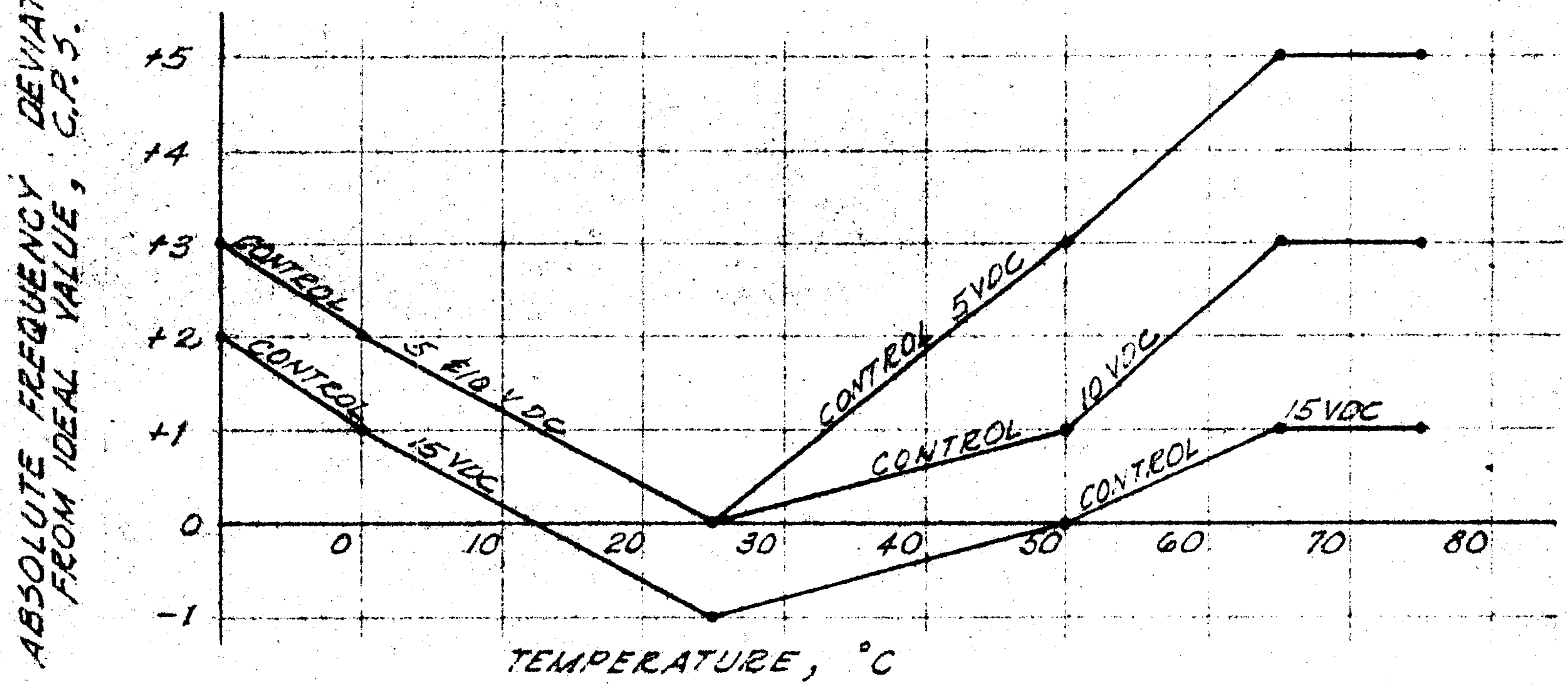


FIGURE 7

VCO CONTROL CHARACTERISTICS

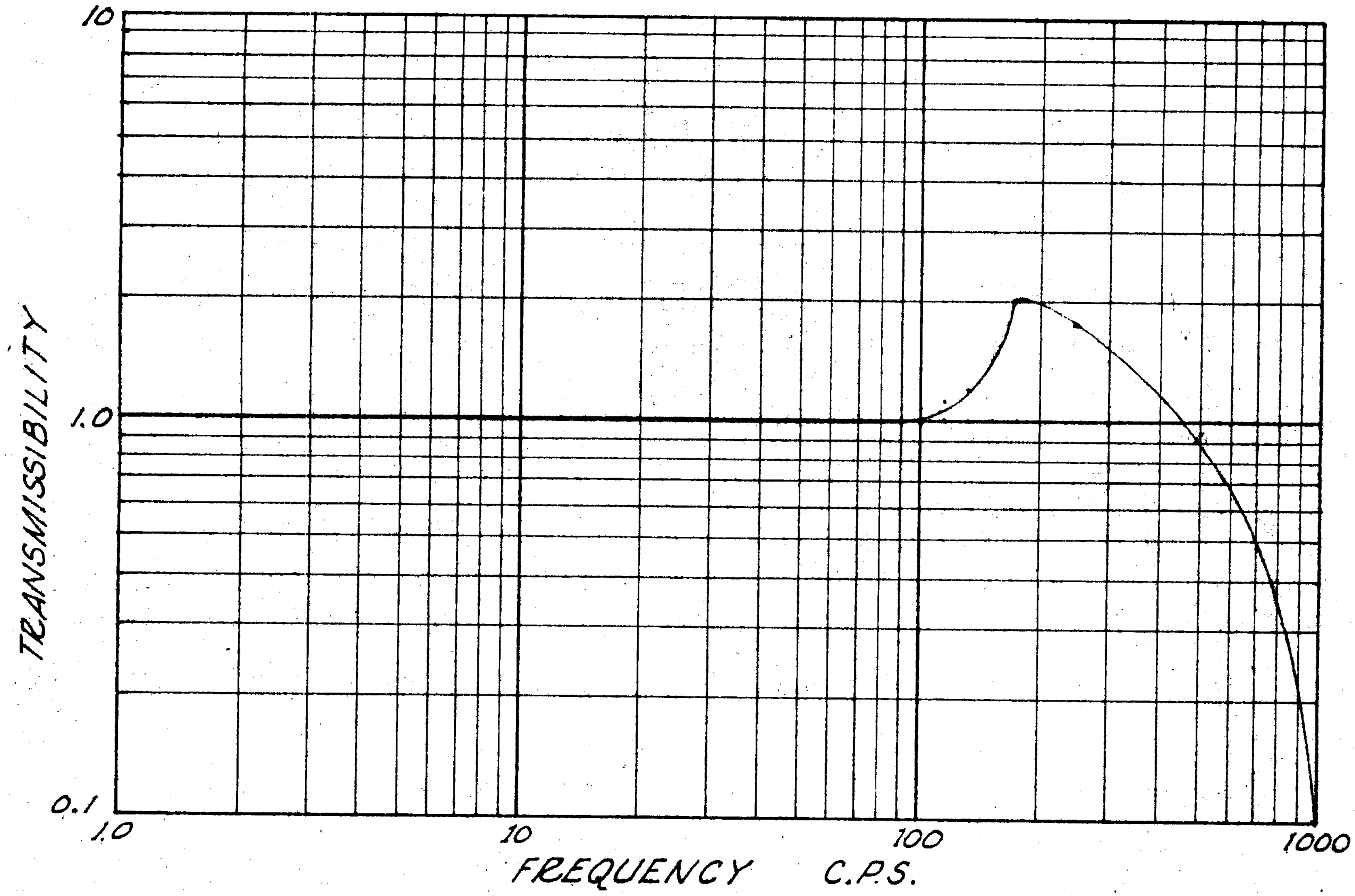


FIGURE 8

VIBRATION ISOLATOR RESPONSE AT 10 G.R.M.S. INPUT – RUBBER IN COMPRESSION.

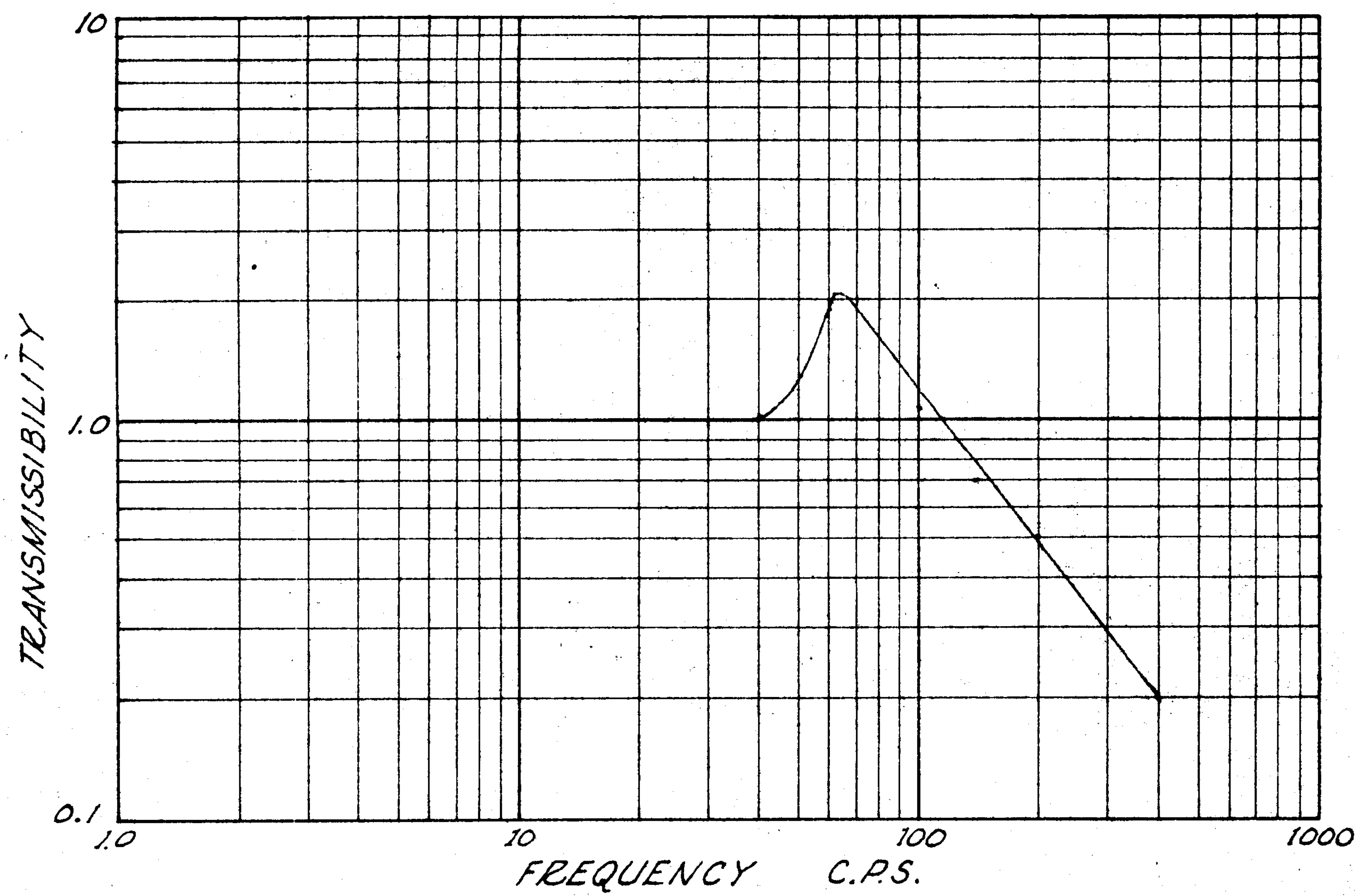


FIGURE 9

VIBRATION ISOLATOR RESPONSE AT 10 G.RMS. INPUT — RUBBER IN SHEAR — VIBRATION PARALLEL TO LONG DIMENSION.

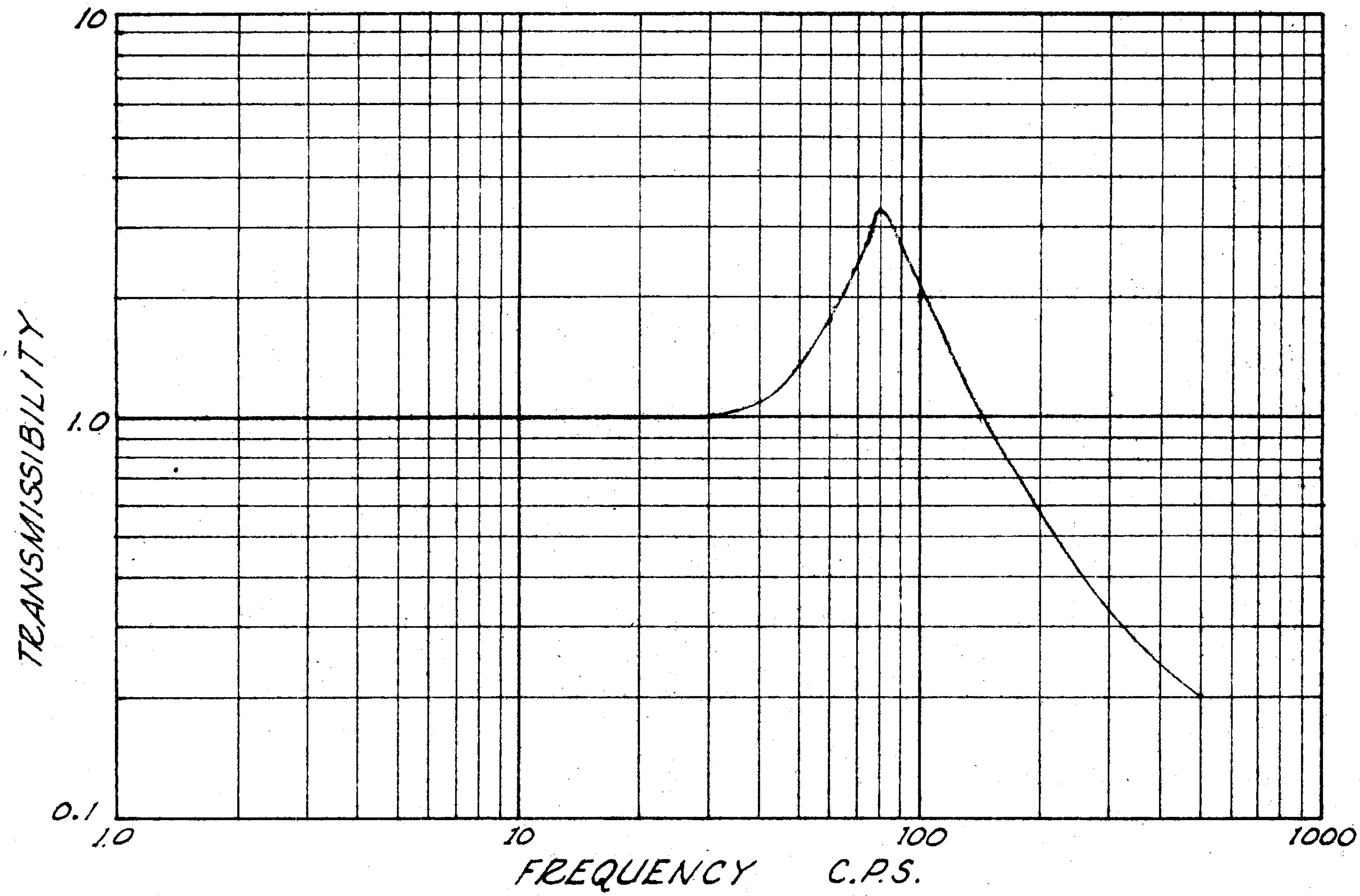
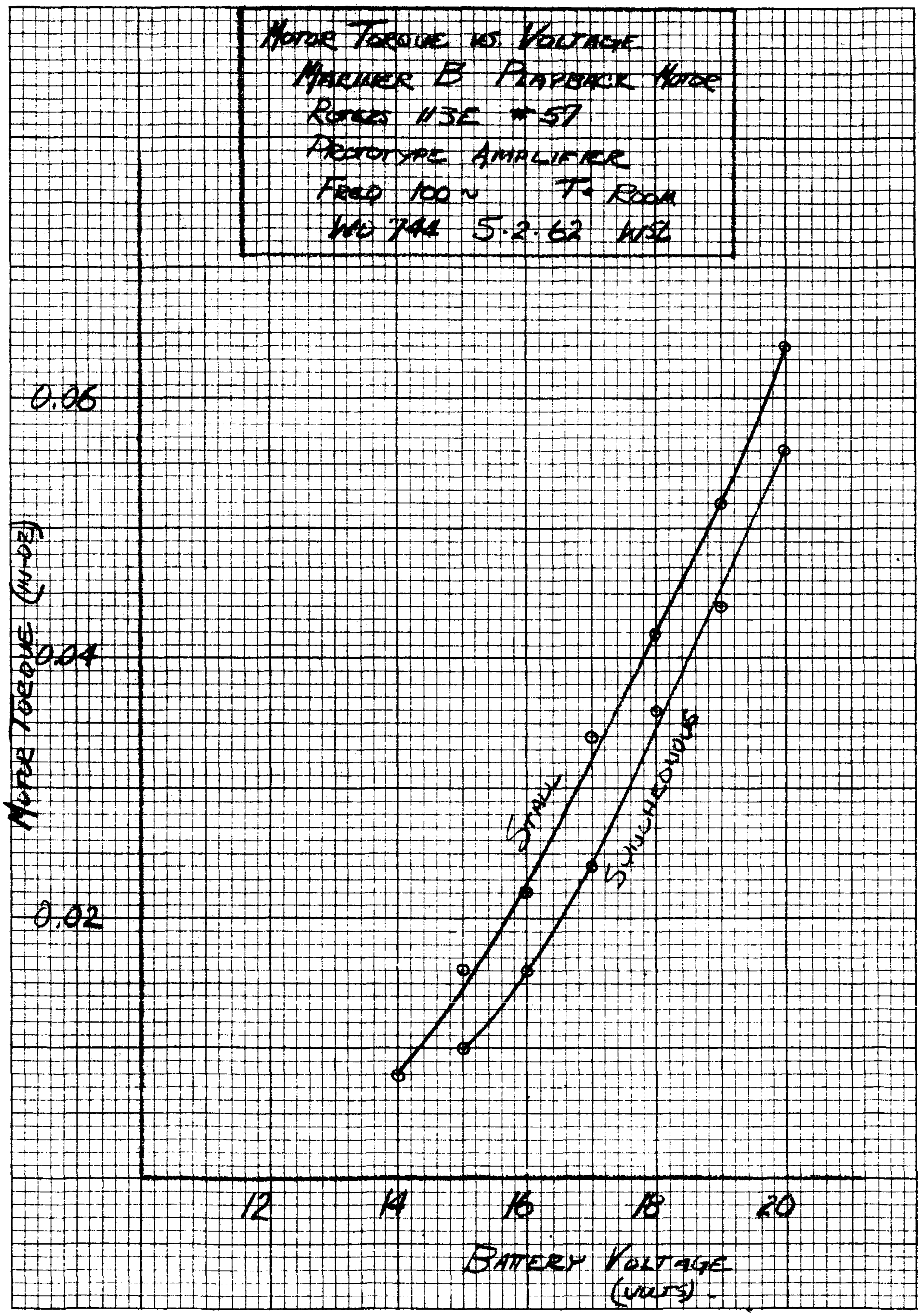


FIGURE 10

VIBRATION ISOLATOR RESPONSE AT 10 G.R.M.S. INPUT – RUBBER IN SHEAR – VIBRATION PARALLEL TO SHORT DIMENSION.

Final Engineering Report
Jet Propulsion Laboratory
REL Report No. 607, REL W.O. 744

MOTOR CURVES AND DATA SHEETS


MOTOR TORQUE VS. VOLTAGE
MARINER B PLAYBACK MOTOR
ROTORS 113E #57
PROTOTYPE AMPLIFIER
FREQ 100~ T= ROOM
5-2-62
0.06
0.04
0.02
MOTOR TORQUE (IN-OZ)
STALL
SYNCHRONOUS
12
14
16
18
20
BATTERY VOLTAGE (VOLTS)

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 7414
DATE 5-1-62
OPERATOR R. L. Wx
MANUFACTURER H. C. Roberts
Remarks: Edc - 20

MOTOR RATINGS
Speed 2000
Torque 0.04 IN OZ.
Frequency 100
MOTOR S/N 133E #57
AMPLIFIER S/N [illegible]
TEMPERATURE [illegible]

Freq.	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
100~	8.5	170	2000	N.L.			
"	13.9	278	2000-4	0.25 +.03	0.056	83.0	29.9
"	17.1	342	STALL	0.26 +.03	0.058		
93~	10.0	200	2000	N.L.			
"	16.4	328	2000-4	0.35 +.03	0.076	113.0	34.5
"	20.8	416	STALL	0.36 +.03	0.078		
107~	7.7	154	2000	N.L.			
	12.0	240	2000-4	0.17 +.03	0.040	59.3	24.6
	14.1	282	STALL	0.17 +.03	0.040		

Master #518

W.S.Lund:lf
February 5, 1962

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 5-1-62

OPERATOR R.L. WL

MANUFACTURER H.C. Rogers

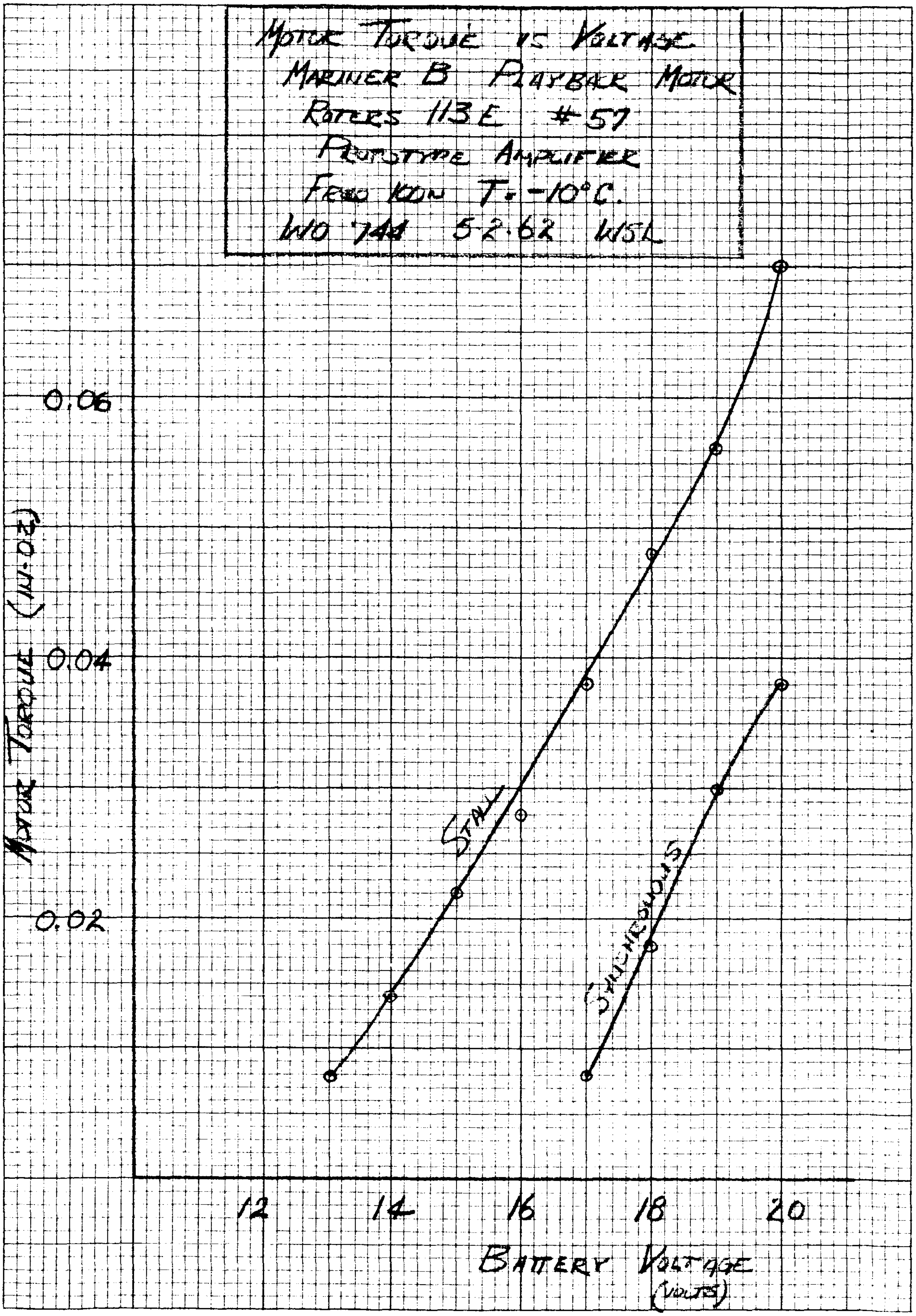
Remarks: Edc = 14-20

MOTOR RATINGS
Speed 2000
Torque 0.09 IN OZ
Frequency 100 ~
MOTOR S/N 113E #57
AMPLIFIER S/N Bread Board
TEMPERATURE Amb.

Edc	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dyna-mometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficienc (%)
20			Sync 2000	0.25+.03	0.056		
19			"	0.19+.03	0.044		
18			"	0.15+.03	0.036		
17			"	0.10+.02	0.024		
16			"	0.06+.02	0.016		
15			"	0.035+.01	0.010		
14			—	—			
20			STALL	0.285+.03	0.064		
19				0.23+.03	0.052		
18				0.18+.03	0.042		
17				0.14+.03	0.034		
16				0.09+.02	0.022		
15				0.06+.02	0.016		
14				0.03+.01	0.008		

Master #518

W.S.Lund:lf
February 5, 1962


MOTOR TORQUE VS VOLTAGE
MARINER B PLAYBACK MOTOR
ROTORS 113E #57
PROTOTYPE AMPLIFIER
FEED IRON T= -10°C.
WO 744 5-2-62 WSL
MOTOR TORQUE (IN-OZ)
0.06
0.04
0.02
STALL
SYNCHRONOUS
12
14
16
18
20
BATTERY VOLTAGE
(VOLTS)

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 5-2-62

OPERATOR R. L. W.

MANUFACTURER H. C. Roters

Remarks: Ed. -20

MOTOR RATINGS
Speed 2000
Torque 0.07 in oz
Frequency [illegible]
MOTOR S/N 113E #57
AMPLIFIER S/N [illegible]
TEMPERATURE -10° C

FREQ.	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
100~	11.6	232	2000	N.L.	—		
"	15.5	310	2000-4	0.16+.03	0.038	56.2	18.1
"	18.5	370	STALL	0.32+.03	0.070		
93~	13.1	262	2000	N.L	—		
"	18.2	364	2000-4	0.28+.03	0.062	91.8	25.2
"	22.4	448	STALL	0.44+.03	0.094		
107~	10.8	216	2000	N.L.	—		
	13.3	266	2000-4	0.06+.02	0.016	23.8	8.94
	15.3	306	STALL	0.24+.03	0.054		

Master #518

W.S.Lund:lf
February 5, 1962

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 5-2-62

OPERATOR [illegible]

MANUFACTURER [illegible]

Remarks: [illegible]

MOTOR RATINGS

Speed 2000

Torque [illegible]

Frequency [illegible]

MOTOR S/N 113E #57

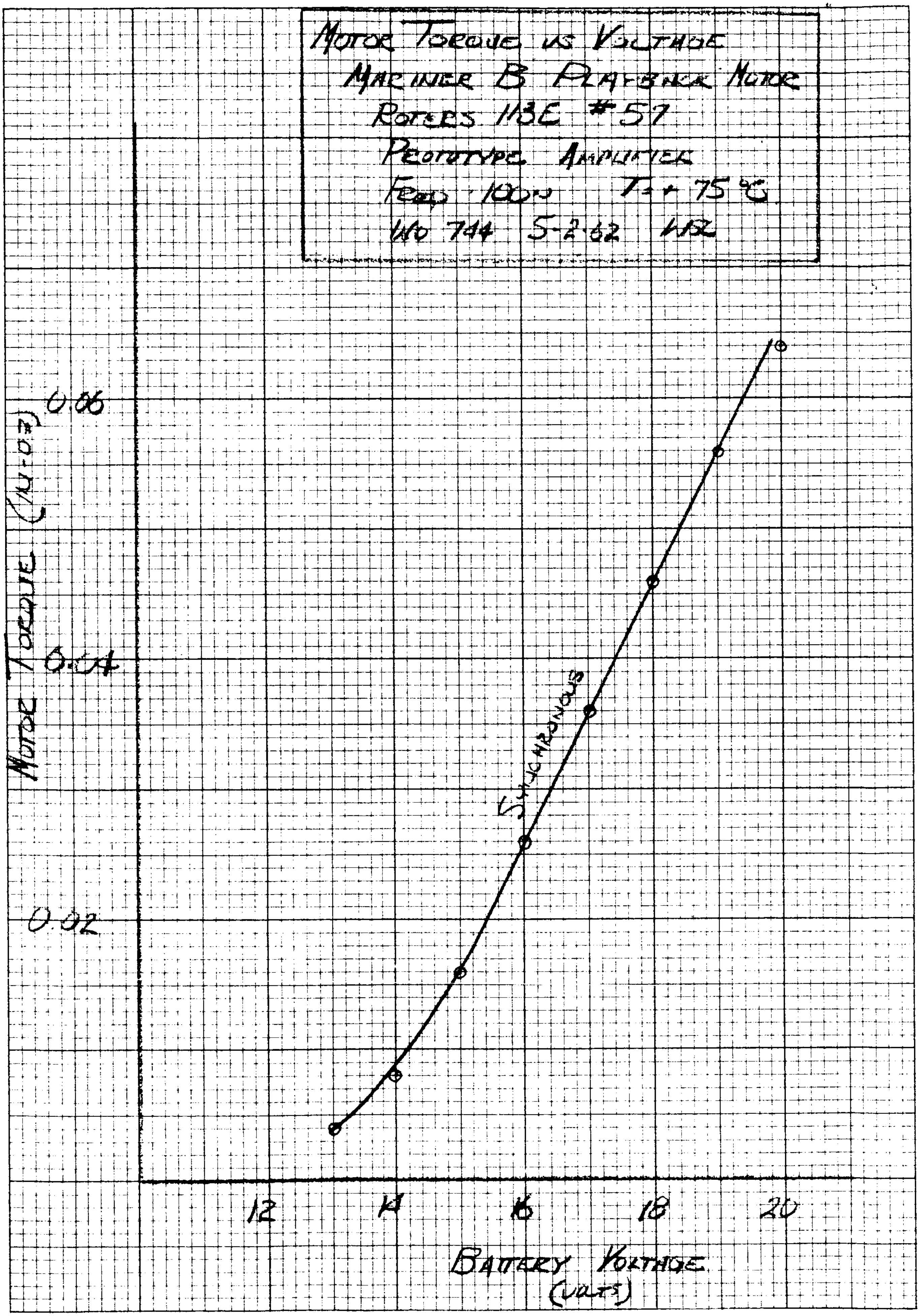
AMPLIFIER S/N [illegible]

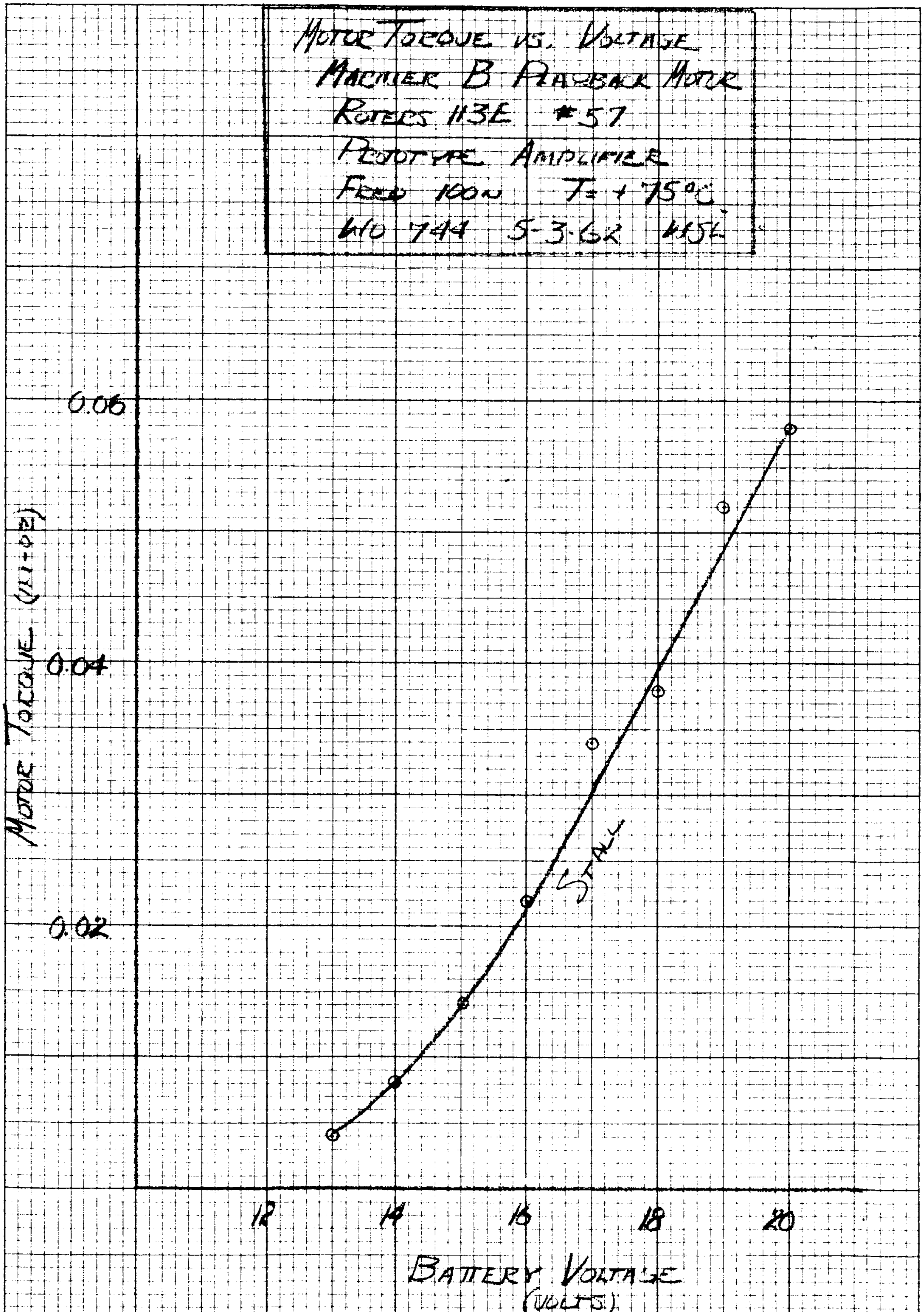
TEMPERATURE -10°C

[illegible]	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
20			STALL	0.32+.03	0.070		
19			"	0.25+.03	0.056		
18			"	0.21+.05	0.049		
17			"	0.16+.03	0.038		
16			"	0.12+.02	0.028		
15			"	0.09+.02	0.022		
14			"	0.06+.01	0.014		
[illegible]			"	0.03+.01	0.00[illegible]		
				—			
20			2000	0.16+.03	0.038		
[illegible]			"	0.12+.03	0.030		
[illegible]			"	0.07+.02	0.016		
[illegible]			"	0.03+.01	0.008		
[illegible]			—	—			
[illegible]							
[illegible]							

Master #518

W.S.Lund:lf
February 5, 1962


MOTOR TORQUE VS VOLTAGE
MARINER B PLAYBACK MOTOR
ROTORS 113E #57
PROTOTYPE AMPLIFIER
FREQ 1000~ T=+75°C
W/O 744 5-2-62
0.06
0.04
0.02
MOTOR TORQUE (IN-OZ)
SYNCHRONOUS
12
14
16
18
20
BATTERY VOLTAGE
(VOLTS)



MOTOR TORQUE VS. VOLTAGE
MACHIER B PLAYBACK MOTOR
ROTEC'S 113E #57
PROTOTYPE AMPLIFIER
FEED 100~ T = +75°C
W/O 744 5-3-62
MOTOR TORQUE (IN-OZ)
0.06
0.04
0.02
STALL
12
14
16
18
20
BATTERY VOLTAGE
(VOLTS)

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 5-2-62

OPERATOR R. C. Wil

MANUFACTURER H. C. Roters

Remarks: S/c =20

MOTOR RATINGS
Speed 2000
Torque 0.04 IN OZ
Frequency 100 ~
MOTOR S/N 113E #57
AMPLIFIER S/N Bread Board
TEMPERATURE +75°C

Batt Volts	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
20			Sync	0.27+03	0.064		
19				0.25+.03	0.056		
18				0.20+03	0.046		
17				0.15+03	0.036		
16				0.10+.03	0.026		
15				0.06+.02	0.016		
14				0.03+.01	0.008		
13				0.01+.01	0.004		
12				0			
20			Sync	0.26+03	0.05[illegible]		
19				0.23+03	0.052		
18				0.16+03	0.038		
17				0.14+03	0.034		
16				0.09+02	0.022		
15				0.06+01	0.014		
14				0.03+01	0.008		
13				0.01+01	0.004		
12							

Master #518

W.S.Lund:lf
February 5, 1962

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 5-2-62

OPERATOR R. L. W[illegible]

MANUFACTURER H. C. ROTERS

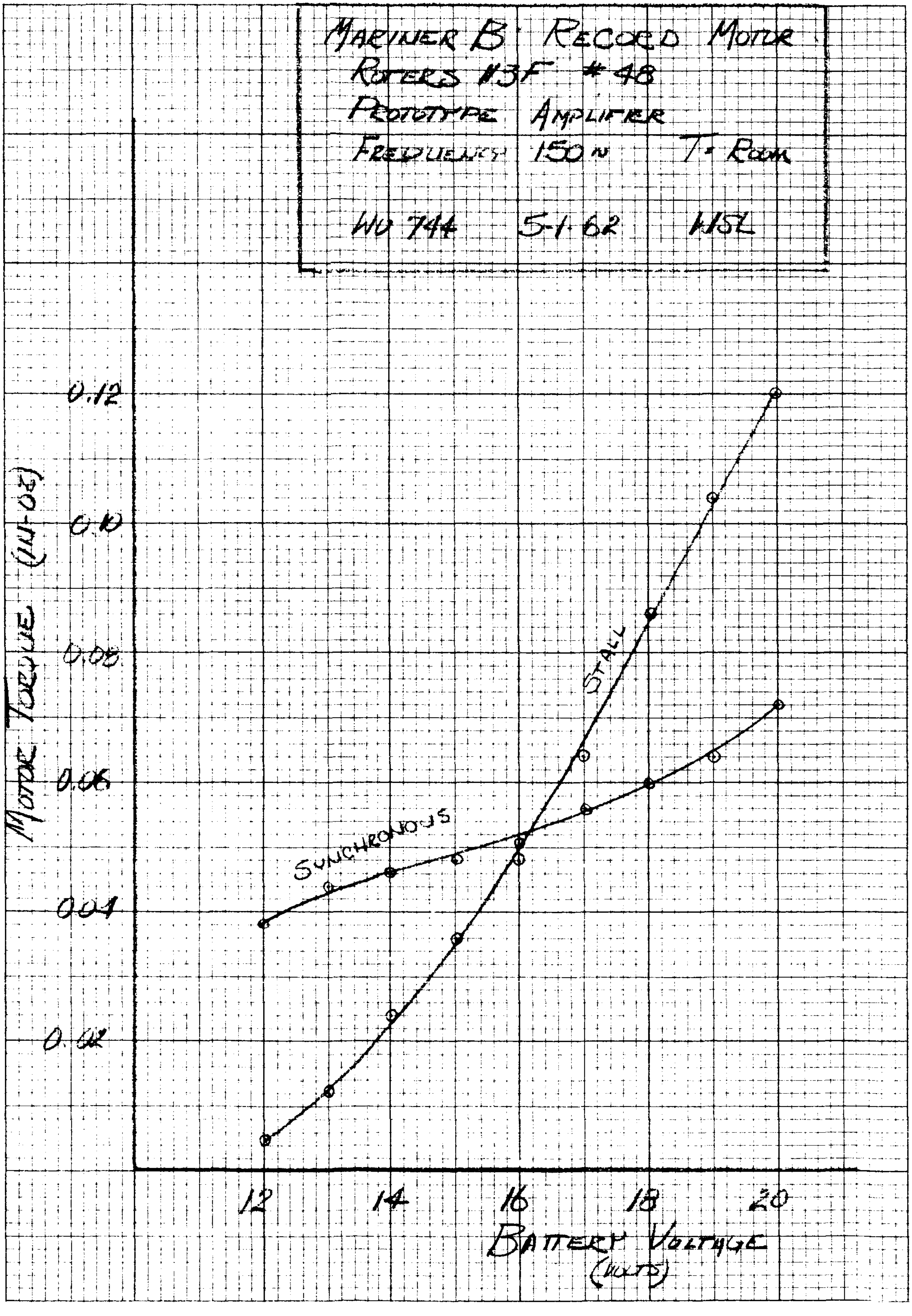
Remarks: E[illegible] 20

MOTOR RATINGS
Speed 2000
Torque 0.04 IN OZ
Frequency 93 - 107 ~
MOTOR S/N 113 E H 57
AMPLIFIER S/N BREAD BOARD
TEMPERATURE + 75°C

FREQ.	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
100 ~	7.5	150	2000	N. L.			
"	13.8	276	2000-4	0.30 + 03	0.066	97.8	35.4
"	17.2	344	STALL	0.26 + 03	0.058		
93 ~	8.9	178	2000	N. L.			
	161	322	2000-4	0.40 + 03	0.080	127.0	39.4
	20.1	41[illegible]	STALL	0.38 + 03	0.082		
107	6.6	132	2000	N. L.			
	12.1	242	2000-4	0.235 + 03	0.054	80.0	33.1
	14.7	314	STALL	0.11 + 03	0.044		

Master #518

W.S.Lund:lf
February 5, 1962


MARINER B RECORD MOTOR
ROTERS #3F #48
PROTOTYPE AMPLIFIER
FREQUENCY 150 ~ T = ROOM
WO 744 5-1-62 WSL
0.12
0.10
0.08
0.06
0.04
0.02
MOTOR TORQUE (IN-OZ)
STALL
SYNCHRONOUS
12
14
16
18
20
BATTERY VOLTAGE
(VOLTS)

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 4-30-62

OPERATOR R L

MANUFACTURER [illegible]

Remarks: 20 V

MOTOR RATINGS

Speed 3000

Torque 0.18 in oz

Frequency [illegible]

MOTOR S/N 133F #40

AMPLIFIER S/N [illegible]

TEMPERATURE Amb. 72°

Battery Voltage (volts)	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
20	29.5	590	3000	NL			
	35.7	715	3000-4	0.325 + oz	0.072		
	45.2	904	STALL	0.55 + oz	0.114		
		Instrumentation		Problem			
RE-RUN			5-1-62				
20	27.7	554	3000	N.L.			
	33.9	678	3000-4	0.34 + oz	0.074	164	21.3
	43.7	875	STALL	0.57 + oz	0.118		

Master #518

W.S.Lund:lf
February 5, 1962

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

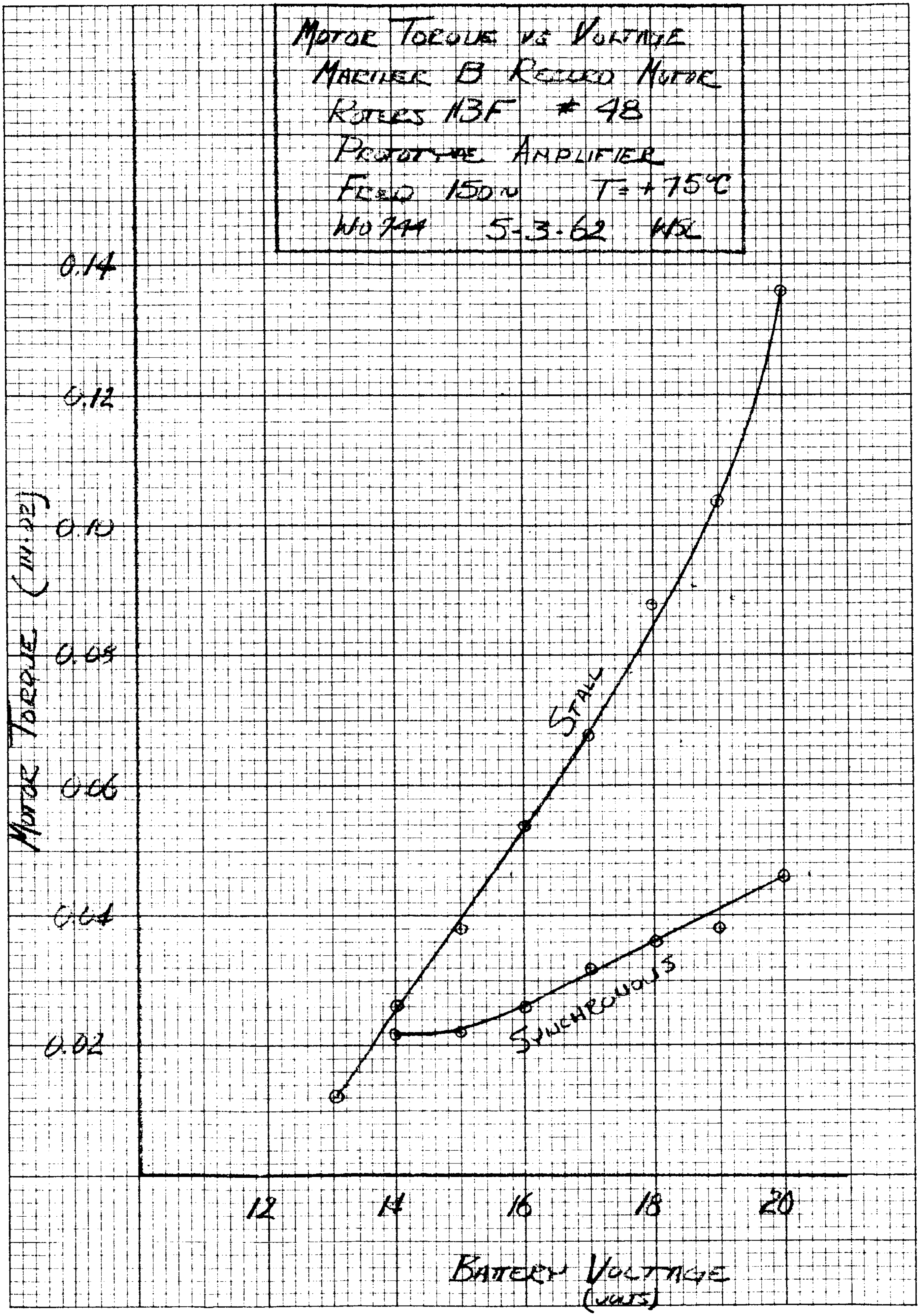
WORK ORDER 744
DATE 5-1-62
OPERATOR [illegible]
MANUFACTURER [illegible]
Remarks:

MOTOR RATINGS
Speed [illegible]
Torque 0.08 [illegible]
Frequency 150 ~
MOTOR S/N 13[illegible] #48
AMPLIFIER S/N [illegible]
TEMPERATURE Amb.

Battery Voltage	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
20			STALL	0.581 + .02	0.120		
19				0.475 + .05	0.104		
18				0.4[illegible] + .03	0.086		
17				0.29 + .03	0.064		
16				0.21 + .03	0.04[illegible]		
15				0.15 + .03	0.036		
14				0.10 + .02	0.024		
13				0.05 + .01	0.012		
12				[illegible]	0.005		
20			3000	0.31 + .03	0.072		
19				0.29 + .03	0.064		
18				0.27 + .03	0.060		
17				0.245 + .03	0.056		
16				0.22 + .03	0.050		
15				0.215 + .03	0.04[illegible]		
14				0.20 + .03	0.046		
13				0.19 + .03	0.044		
12				0.16 + .03	0.038		

Master #518

W.S.Lund:lf
February 5, 1962


MOTOR TORQUE VS VOLTAGE
MARINER B RECORD MOTOR
ROTORS 113F # 48
PROTOTYPE AMPLIFIER
FEED 150 N T = +75°C
WO 744 5-3-62 WSL
0.14
0.12
0.10
0.08
0.06
0.04
0.02
MOTOR TORQUE (IN-OZ)
STALL
SYNCHRONOUS
12
14
16
18
20
BATTERY VOLTAGE (VOLTS)

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 7-[illegible]

DATE 5-3-62

OPERATOR R.L. W[illegible]

MANUFACTURER H. C. Raters

Remarks: Sdc = 20

MOTOR RATINGS
Speed 3000
Torque 0.08 in oz
Frequency 150 ~

MOTOR S/N 113F #47

AMPLIFIER S/N [illegible]

TEMPERATURE + 75° C

	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
	31.4	628	3000	N.L.	N.L.		
	34.5	690	3000-1	0.24+.03	0.054	120	17.4
	50.2	1004	Stall	0.65+.03	0.136		

Master #518

W.S.Lund:lf
February 5, 1962

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 5-3-62

OPERATOR [illegible]

MANUFACTURER [illegible]

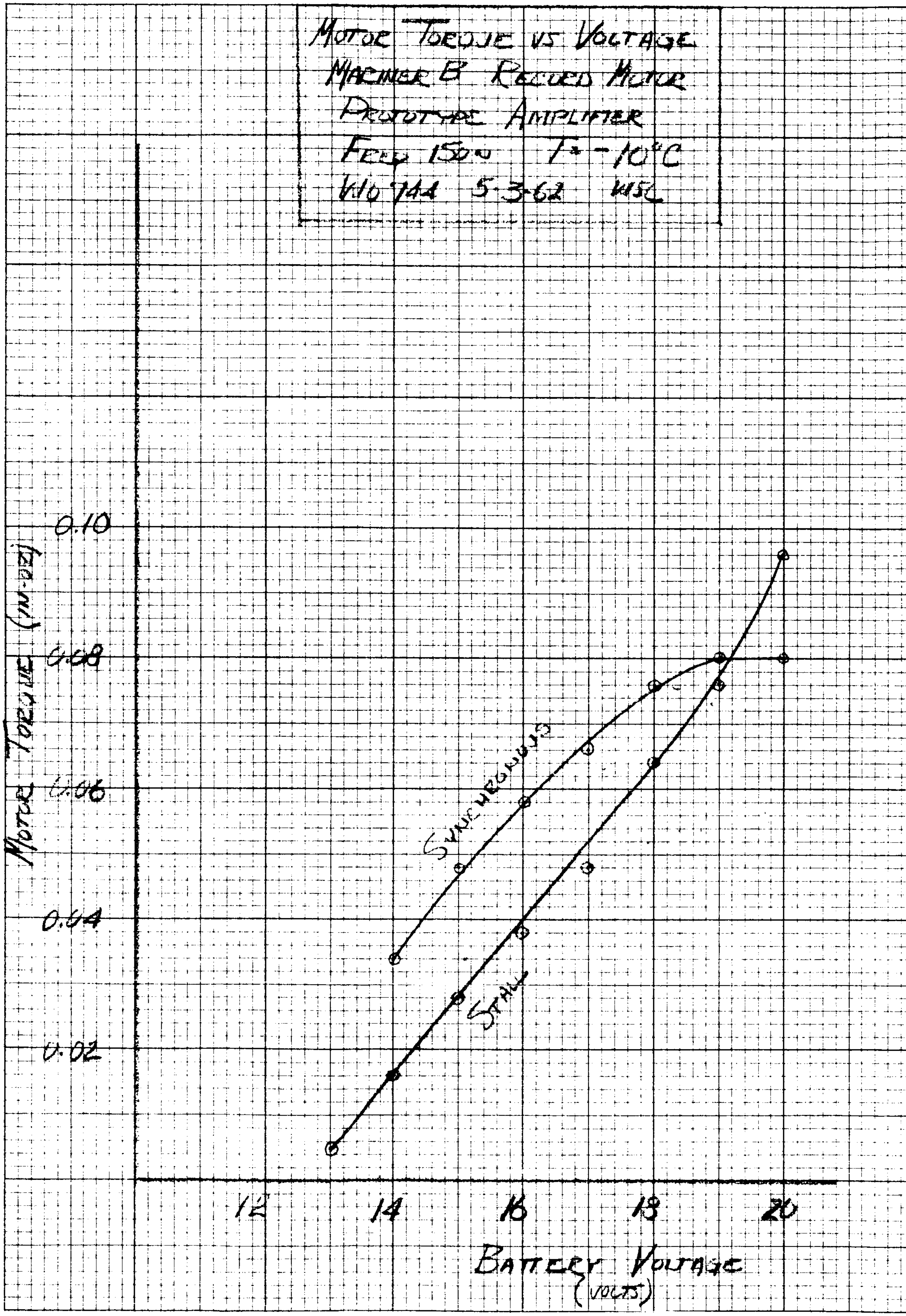
Remarks: [illegible] = 12-20

MOTOR RATINGS
Speed 3000
Torque [illegible] 8 [illegible]
Frequency 150 [illegible]
MOTOR S/N 113F #48
AMPLIFIER S/N [illegible]
TEMPERATURE +75°C

	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dyna-mometer Reading (in-oz)	Motor Torque Actual (in-oz)	~~Shaft Power Out~~ TORQUE (Milli watts)	~~Motor Efficienc~~ ACTUAL TORQUE ~~(%)~~ IN-OZ
20			SYNC	0.17		0.65+.03	0.136
19			"	0.16		0.49+.03	0.104
18			"	0.15		0.41+.03	0.08[illegible]
17			"	0.14		0.31+.03	0.068
16			"	0.12		0.24+.03	0.054
15			"	0.11		0.16+.03	0.038
14			"	0.08		0.10+.03	0.026
13				0.05		0.04+.02	0.012
12				0.02		0.01+.01	0.004
20			Sync.	0.20+.03	0.046		
19				0.16+.03	0.038		
18				0.15+.03	0.036		
17				0.13+.03	0.032		
16				0.10+.03	0.026		
15				0.09+.02	0.022		
14				0.01+.02	0.022		
13				0.13			
12			"	0.15			

Master #518

W.S.Lund:lf
February 5, 1962


MOTOR TORQUE VS VOLTAGE
PROTOTYPE AMPLIFIER
5-3-62
0.10
0.08
0.06
0.04
0.02
MOTOR TORQUE (IN-OZ)
SYNCHRONOUS
STALL
12
14
16
18
20
BATTERY VOLTAGE
(VOLTS)

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 5-3-62

OPERATOR R.L. WL

MANUFACTURER H.C. [illegible]

Remarks: Edc = 20

MOTOR RATINGS
Speed 3000
Torque 0.08 in oz
Frequency 150 ~
MOTOR S/N 113 F 48
AMPLIFIER S/N R.L. Watts
TEMPERATURE -10°C

	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficienc (%)
150 ~	25.9	518	2000	N.L.	N.L.		
"	31.9	638	2000-4	0.37+.03	0.080	177	27.9
"	42.3	846	STALL	0.45+.03	0.096		

Master #518

W.S.Lund:lf
February 5, 1962

Raymond Engineering Laboratory
Middletown, Connecticut

MOTOR EVALUATION

WORK ORDER 744

DATE 5-3-62

OPERATOR R. L. [illegible]

MANUFACTURER H. C. MOTORS

Remarks: 5dc = 12 - 20

MOTOR RATINGS
Speed 3000
Torque 0.08 IN OZ
Frequency 150 ~

MOTOR S/N 113F #48

AMPLIFIER S/N 3.2 (Corp)

TEMPERATURE -10° C

	Battery Current (ma. DC)	Power Input (Milli watts)	Shaft Speed (RPM)	Motor Torque Dynamometer Reading (in-oz)	Motor Torque Actual (in-oz)	Shaft Power Out (Milli watts)	Motor Efficiency (%)
20			STALL	.45 + .03	.096		
19			"	.35 + .03	.076		
18			"	.21 + .03	.064		
17			"	.21 + .03	.048		
16			"	.16 + .03	.038		
15			"	.11 + .05	.028		
14			"	.06 + .02	.016		
13			"	.013 + .01	.005		
12			"	—			
20			Sync.	0.37 + .03	0.080		
19			"	0.37 + .03	0.080		
18			"	0.35 + .03	0.076		
17			"	0.30 + .03	0.066		
16			"	0.25 + .03	0.056		
15			"	0.21 + .03	0.048		
14				0.14 + .03	0.034		
13			—	—			
12							

Master #518

W.S.Lund:lf
February 5, 1962

Final Engineering Report
Jet Propulsion Laboratory
REL Report No. 607, REL W.O. 744

ENGINEERING DRAWING LIST

W.O. 744 - (JPL)

10^6 Bit Engineering Data Recorder Drawing List

Number	Title
D1656-1	Assembly - Recorder - Mariner "B"
D1656-2	Outline Dimensions - #744 Tape Recorder
C1656-3	Tape Drive Systems
B1656-4	Electronic Card Holder
E1656-5C	Plate - Transport Mariner "B"
C1656-6	Timer Assembly - Mariner "B"
A1656-9	Assembly Cam Shaft & Gear
C1656-10	Tape Reel Assembly
B1656-11-1A & 2A	Assembly Pulley
C1656-12	Capstan Assembly
C1656-13-1 & 2	Assembly Idler
C1656-14	Assembly Pressure Roller
B1656-15	Schematic Diagram Phase - Locked - Loop
D1656-16B	Recorder Block Diagram
D1656-17B	Control & External Connector Schematic Diagram
B1656-18A	NRZ Amplifiers Schematic Diagrams
B1656-19	Dual & - Invert Gate Schematic Diagram
B1656-20	Flip Flop (RST) Schematic Diagram
C1656-21	NRZ Track & Word Sync Head Drivers - Schematic Diagram
C1656-22	Power Amplifier 1 Schematic Diagram
C1656-23	Power Amplifiers 3 & 4 Schematic Diagram
D1656-24	Pulse Amplifier 1 & 2 Schematic Diagram
B1656-25	NRZ Flip Flop Schematic Diagram
C1656-26	Delay Flip Flop Schematic Diagram
B1656-27	Unijunction VCO Schematic Diagram
C1656-28	Integrator, Phase Comparator and Integrator Reset Schematic Diagram
C1656-29	Integrator Board - Fabrication
D1656-30	Module & Pwr. Amplifier Board - Fabrication Drawing
D1656-31	Transistor & Transformer Locations - Modules & Pwr. Amplifiers Board
D1656-32	Terminal Locations - Modules & Pwr. Ampls. Board
C1656-33	Pulse Amplifiers Board - Fabrication
A1656-34	Transformer Bracket - Large
A1656-35	Transformer Bracket - Small
B1656-36	Connector Shield - Pulse Amplifier Board
A1656-37	Connector Post - Pulse Amplifier Board
A1656-38	Connector Bracket - Pwr. Amplifier Board
A1656-39	Connector Post - Integrator Board
B1656-40	Brackets - Relay Mounting

Number	Title
C1656-41	Board - Terminal & Relay Mounting
A1656-42	Playback Head
A1656-43	Record Head
C1656-44	Small Cover - Power Amplifier Board
C1656-45	Large Cover - Power Amplifier Board
C1656-46	Assembly - Relay Board
C1656-47	Small Cover - Pulse Amplifier Board
C1656-48	Large Cover - Pulse Amplifier Board
A1656-49	Spacer
A1656-50	Spacer
1656-51	No Drawing
1656-52	No Drawing
B1656-53C	Cam Shaft
1656-54	No Drawing
1656-55	No Drawing
1656-56	No Drawing
D1656-57	Cover
A1656-58	Shaft - Torsion Spring
B1656-59	Motor Mount
B1656-60C	Pulley
B1656-61	Shaft, Idler
B1656-62-1A & 2A	Capstan
B1656-63-1 & 3	Pulley
B1656-63-2	Pulley
B1656-64B	Pulley
B1656-65C	Flywheel
C1656-66A	Housing Bearing
1656-67	No Drawing
A1656-68A	Mount Head
1656-69	No Drawing
1656-70	No Drawing
B1656-71-1 & 2	Plate, Timer
B1656-72C	Bottom Timer Plate
B1656-73A	Cleat
B1656-74	Cleat - Motor
A1656-75A	Roller - Tape
A1656-76	Shaft - Reel
A1656-77	Plate - Reel
B1656-78	Reel
C1656-79A	Housing - Reel
D1656-80E	Plate - Reel
B1656-81-1A through 12A	Spacer - Precision Duplex Bearing
B1656-82-1	Pulley Timer
A1656-83	Key
A1656-84	Spacer
B1656-85	Pulley - Pressure Belt
A1656-86C	Belt
A1656-87A	Pressure Belt
A1656-88B	Spacer, Switch
1656-89	No Drawing
A1656-90	Felt Pad
1656-91	No Drawing
1656-92	No Drawing

Number	Title
A1656-93	Wiper, Spring
B1656-94	Holder, Spring Wiper
A1656-95	Spacer Tape
A1656-96A	Guide Tape
A1656-97	Valve
B1656-98	Plate - Seal
B1656-99	Cap - Valve
A1656-100	Seal - Valves
A1656-101A	Cam - Switch
A1656-102A	Mount, Head
A1656-103B	Mount, Head
A1656-104	Electronics Board - Timer
A1656-105	Spacer - Pulse Amplifier Bd.
A1656-106	Spacer - Relay Board
A1656-107	Spacer - Timer
A1656-108	Spacer - Timer
D1656-109	Wiring Diagram Mariner "B"
B1656-110	Mechanical Assembly Mariner "B"
B1656-111	Assembly - Vibration Isolator
A1656-112	Assembly - Valve & Seal Plate
A1656-113	Bracket - Timer
A1656-114	Cable Clamp
A1656-115	Cable Clamp
A1656-116	Assembly - Electronics Board Timer
D1656-117	Assembly - Electronics Mariner "B"
C1656-118	Assembly - Integrator, Integrator Reset, Phase Comparator, Unijunction VCO, NRZ Input & Output Amp.
C1656-119	Assembly Pulse Amp. 1 & 2 and NRZ Flip Flop Board
D1656-120	Assembly Power Amp. & Module Board
A1656-121	Spacer Pwr. Ampl. Bd.
A1656-122	Assembly - Spring Wiper
A1656-123	Cable Clamp - Head Leads
B1656-124	Adapter Plate - Vibration Fixture
B1656-125	Small Mounting Pl. - Vibration Fixture
B1656-126	Rubber Cushion - Vibration Fixture
B1656-127	Large Mounting Pl. - Vibration Fixture

SUPPLEMENTARY LIST

The following supplementary list denotes standard hardware or parts designed for other programs.

Number	Title
A132870	Process for Seal Potting End Cover
A1101-8	Gear and Pinion Assembly
A1101-9	Gear and Pinion Assembly
A1360-1-36	Insert Male Plug - 15 Pin
A1360-1-37E	Connector
A1360-2-1	Soldering Lug
A1360-6-7	Screw - Flat Head Machine
A1360-6-9	Screw - Flat Head Machine
A1360-6-10	Flat Head Screw
A1360-6-22	Screw - Machine, Flat Head 82°
B1360-9	Screw, Binding Head
B1360-9Z	Screw, Binding Head
A1360-10	Screw - Soc. Hd. Cap
A1360-10Z	Screw - Soc. Hd. Cap
A1360-11	Washer - Plain
A1360-12-7	Nut, Self-locking
A1360-14-3	Rivet, Oval Head
A1360-18-2	Micro-switch
A1360-21-5	Ring - Retainer
A1360-21-6	Ring, Retaining
A1360-21-7	Retaining Ring, Internal
A1360-27-3	Setscrew - Socket Hd.
A1360-41-1	Actuator Micro-Switch
A1360-45	Nut - Machine Screw
A1360-46C	Screw, Self-locking
A1360-56-13	Ball Bearing
A1360-56-42D	Ball Bearing Duplex Pair
A1515-155A	Shaft - Roller
A1515-204	Insert - Clutch
A1598-20	Retainer, Bearing
A1598-21	Retainer, Bearing
B1631-212-1A & 2A	Housing - Thermistor
A AN500	Screw, Machine, Fillister Head, Coarse Thread
A MS15795	Washers, Flat, Metal, Round, General Purpose
A MS35338	Washer, Lock, Split, Helical, Medium Series
A MS 35249	Screw, Machine, Flat Countersunk, Head Slotted, Corrosion Resisting Steel
A MS35649	Nut, Plain, Hexagon, Machine Screw
A MS35233	Screw Machine, Pan Head, Slotted Corrosion Resisting Steel
A MS35240	Screw, Machine, Flat Countersunk Hd., Slotted
B1598-32	Spring, Clutch (Over Running)
A1690-129	Retaining Bearing
A1690-131	Retaining Bearing
A1700-53	Post - Connector Mounting
A1700-89	62 Teeth Gear